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Monterey, California

THESIS

METOC AND NAVAL AFLOAT OPERATIONS:
RISK MANAGEMENT, SAFETY, & READINESS

by

Brett S. Martin

December 2002

Thesis Advisor:	Tom Murphree
Second Reader:	Carlyle H. Wash

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2002	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: METOC and Naval Afloat Operations: Risk Management, Safety, & Readiness			**5. FUNDING NUMBERS**
6. AUTHOR(S) Martin , Brett S.			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT ***(maximum 200 words)***

We have investigated the METOC aspects of ORM, safety, and readiness in Naval afloat operations. The purpose of this work was to identify and develop methods by which the METOC community can better contribute to these components of Naval operations. Records of class A, B and C afloat mishaps during March 1997 – March 2002 from the NSC were the primary data source for this study. Our major objectives in analyzing this data were to identify: (1) METOC related mishaps (MRMs); (2) the costs of these mishaps; and (3) the phenomenological and operational conditions under which these mishaps occurredWe identified 166 MRMs during the study period. The major average costs of these mishaps were: (1) 1.5 deaths per year; (2) 16 days of lost duty per MRM; (3) 11 days of light duty per MRM; (4) 150 days of lost or light duty per year due to MRMs involving small boat operations; and (5) $54,000 in equipment damage per MRM. The major METOC phenomena involved in underway MRMs were high winds and seas, which occurred in over half the MRMs. 84% of the MRMs involved deficiencies in training on how to deal with adverse METOC conditions.

14. SUBJECT TERMS Naval Afloat Mishaps, METOC Phenomena, Human Error, Accident Classification, Accident Analysis, Surface Weather, Operational Risk Management (ORM), Readiness			**15. NUMBER OF PAGES** 96
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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METOC AND NAVAL AFLOAT OPERATIONS: RISK MANAGEMENT, SAFETY, & READINESS

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Lieutenant Commander, United States Navy
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY AND PHYSICAL OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

We have investigated the meteorology and oceanography (METOC) aspects of operational risk management (ORM), safety, and readiness in Naval afloat operations. The purpose of this work was to identify and develop methods by which the METOC community can better contribute to these components of Naval operations. Records of class A, B and C afloat mishaps during March 1997 – March 2002 from the Naval Safety Center (NSC) were the primary data source for this study. Our major objectives in analyzing this data were to identify: (1) METOC related mishaps (MRMs); (2) the costs of these mishaps; and (3) the phenomenological and operational conditions under which these mishaps occurred

We identified 166 MRMs during the study period. The major average costs of these mishaps were: (1) 1.5 deaths per year; (2) 16 days of lost duty per MRM; (3) 11 days of light duty per MRM; (4) 150 days of lost or light duty per year due to MRMs involving small boat operations; and (5) $54,000 in equipment damage per MRM. The major METOC phenomena involved in underway MRMs were high winds and seas, which occurred in over half the MRMs. Rain was the major phenomenon involved in privately operated vehicle (POV) mishaps. 84% of the MRMs involved some type of deficiency in training on how to deal with adverse METOC conditions. For most MRMs, the mishap records did not provide enough information to determine if a METOC forecast and/or brief was provided prior to the mishap. During 1997 – 2001 there was a declining trend in tropical cyclone (TC) related mishaps, especially in the western Pacific. Preliminary analyses suggest this trend may be an indication of improvements in TC forecasting, and therefore a potential metric of increased METOC contributions to afloat ORM, safety, and readiness.

One of the products of this study is a training module on operating small boats under various wind and sea states. We identified the need for this module from our analyses of the MRMs, and from consulting with colleagues at NSC, North Atlantic Meteorology and Oceanography Center (NLMOC), Surface Warfare Officer School (SWOS), Expeditionary Warfare Training Group, Atlantic (EWTGLANT), and Marine

Rescue Consultants. Upon completion, this module will be distributed to the fleet through the SWOS Department Head Training program. We expect this module to be useful in homeland security and Northern Arabian Gulf (NAG) operations by contributing to improved ORM, safety, and readiness associated with boarding, searching, and seizure operations. Another product, our MRM database, has been transferred to NLMOC where it has been used in a separate study of the effectiveness of Optimal Track Ship Routing (OTSR). Based on our findings, we have developed a set of recommendations for how the METOC community can better meet its afloat customers' needs, and thereby increase the overall METOC contribution to real world operations. We will submit to NSC our recommendations on how to improve the METOC aspects of investigating and reporting afloat mishaps.

The major accomplishments of this study are: (1) the development of a database of METOC related mishaps that can be used for future studies; (2) the development of recommendations for the METOC, Afloat, and Safety communities; (3) the initial development of risk management, safety, and readiness metrics for the METOC community; (4) the development of a baseline data set for quantifying future contributions of METOC community; and (5) the identification of the need for, and the development of, a METOC related training module for the afloat community.

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LIST OF ACRONYMS

CNMOC	Commander Naval Meteorology and Oceanography
CNS	Central Nervous System Command
COMNAVSAFCEN	Commander Naval Safety Center
EWTGLANT	Expeditionary Warfare Training Group, Atlantic
GMT	General Military Training
ISIC	Immediate Superior In Command
JTWC	Joint Typhoon Warning Center
LCAC	Landing Craft Air Cushioned
METOC	Meteorology and Oceanography
MIB	Mishap Investigation Board
MIREs	Mishaps Investigation Report Endorsements
MIRs	Mishap Investigation Reports
MOVREP	Movement Report
MRM	METOC Related Mishap
MRs	Mishap Reports
MSC	Military Sealift Command
NAG	Northern Arabian Gulf
NAVOSH	Naval Occupational Safety and Health
NHC	National Hurricane Center
NHC	National Hurricane Center
NLMOC	Naval Atlantic Meteorology and Oceanography
NSC	Naval Safety Center
NTPs	Navy Tactical Publications
NWP	Naval Warfare Publication
OPORDs	Operational Orders
Ops	Ordnance Publications
ORM	Operational Risk Management
OTSR	Optimum Track Ship Routing
PMS	Preventive Maintenance Schedule
PMT	Practical Man Test
POIS	Pulmonary Over Inflation Syndrome
POV	Privately Operated Vehicle

SAR	Search and Rescue
SEAOPS	Safe Engineering and Operations of LCAC\
SOH	Safety and Occupational Health
SWOS	Surface Warfare Officer School
TC	Tropical Cyclone
USCG	United States Coast Guard

GLOSSARY OF SPECIAL TERMS

Class A Mishap: A mishap in which the total cost of reportable damage is $1 million or more; or any injury or work-related illness resulting in death or permanent total disability.

Class B Mishap: A mishap in which the total cost of reportable property damage is $200,000 or more, but less than $1 million; an injury or work-related illness resulting in permanent partial disability; or a mishap resulting in the hospitalization of three or more people.

Class C Mishap: A mishap in which the total cost of reportable property damage is $20,000 or more, but less than $200,000; or an injury or disability preventing personnel from performing regularly scheduled duty for 5 days (1 day for embarked Marines) or more after 2359 hours on the day of the injury or onset of illness.

Evolution: A movement, or a series of movements, of troops or ships, as for disposition in order of battle or in line on parade. An event or operation.

Light Duty Day: Any day that a crewmember has an injury or a disability that prevents him/her from performing regularly scheduled duty, but he/she is still are on the job in a diminished capacity.

Lost Duty Day: Any day that a crewmember has an injury or a disability that prevents him/her from being on the job.

Mishap Investigation Board (MIB): For all afloat Class A mishaps the immediate superior in command, or other higher authority, appoints a MIB. The board's purpose is to investigate the mishap to determine the causes. The board then prepares a Mishap Investigation Report (MIR) with its findings, conclusions, or recommendations.

Mishap Investigation Report (MIR): A formal investigation report for all Class A afloat mishaps that contains the findings, conclusions, or recommendations from a Mishap Investigation Board.

Mishap Report (MR): A report that analyzes and assesses the cause of a mishap. Causes fall into four categories: human, procedural, equipment/material, and design factors. Commanding officers are encouraged to submit a MR with lessons for otherwise non-reportable mishaps that could benefit other ships, such as for minor mishaps or near mishaps. Design or material defects that caused a mishap should be highlighted.

METOC Affected Operations: Fleet activities that are directly affected by METOC phenomena and/or METOC operations, such as: war fighting operations (aviation, amphib, ISR, etc.); the design and use of communication, navigation, and weapons

systems; operation of motor vehicles; mission planning and ORM; education and training; etc.

METOC Operations: The activities of the METOC community, such as monitoring, analyzing, and forecasting METOC phenomena; providing METOC briefs and other products and services to fleet customers; etc.

METOC Phenomena: Atmospheric and oceanographic conditions, such as wind, clouds, rain, haze, etc.

METOC Related Human Safety Factor: A deficiency in the efforts of individuals or groups of people to contend with METOC risks. METOC related human safety factors create hazardous conditions and may cause mishaps.

METOC Related Mishap (MRM): A mishap in which one or more of the following contributed to the mishap:

a. METOC phenomena
b. deficiencies in METOC operations, including deficiencies in the creation and dissemination of METOC products and services
c. deficiencies in the use of METOC products and services to assess and manage METOC risks
d. deficiencies in education and training on assessing and managing METOC risks

METOC Related Operational Risk Management (MRORM): The same process as conducted for ORM, but with a special emphasis being given to hazardous METOC phenomena, METOC operations, and METOC affected operations.

METOC Risks: Risks created by METOC phenomena that have the potential to interfere with successful and safe completion of an operation. Also known as METOC Hazards or METOC Risk Factors

Operational Risk Management (ORM): ORM is a process in which people at all levels increase their operational effectiveness by:

a. anticipating hazards
b. identifying and implementing methods for reducing the risks imposed by those hazards

The goal of ORM is to increase the probability of a successful mission by anticipating and managing all the risks involved in that mission. ORM involves a five step process:

a. Identify Hazards
b. Assess Hazards
c. Make Risk Decisions
d. Implement Controls
e. Supervise

These five steps can be abbreviated and memorized using the first letters of each step: I AM IS.

Practical Man Test (PMT): A method for determining whether a mishap was a MRM. The three possible answers for any mishap are: Yes, No, Maybe. For this study, the PMT was conducted by an experienced Naval officer who is, or has been: a Surface Warfare Officer, a METOC Officer, and an Afloat Safety Officer. Many of the PMT outcomes of this study were checked and confirmed by other Naval officers with comparable experience.

Readiness: A state of preparedness in which ship or organization is capable of conducting a mission and is ready to deploy.

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ACKNOWLEDGMENTS

The author would like to acknowledge and express gratitude to Professor Murphree and Professor Wash for their guidance and assistance in the completion of this research. It was a privilege and an honor to work with them on this project. The author also appreciates in part the support provided by The Office of Naval Research under the project, Collaborative Research Projects in Support of FNMOC and CNMOC. The author also would like to recognize the support provided by Captain Bacon, Steve Scudder, LCDR Jake Hinz, Ed Altimari, Steven Wigley, Larry Gibson, and Nancy Sharrock. In addition, I would like to thank the fellow officers who gave me guidance and helped me analyze the MRs and MIRs: CAPT J. Bacon, CDR A. Jacobs, CDR (Ret) M. McMaster, LCDR J. Hinz, Lt Col R. Nichols, CDR J. Joseph, It Cdr Andy Moys, Royal Navy, and LT C. Gahard. This thesis would not have been possible without the support of the Naval Safety Center, and the Marine Rescue Consultants, LLC. Sincere appreciation is due to my loving wife Karen, family, Rusty, Roxy and Comanche whose devotion and support is never ending.

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EXECUTIVE SUMMARY

We have investigated the meteorology and oceanography (METOC) aspects of operational risk management (ORM), safety, and readiness in Naval afloat operations. The purpose of this work was to identify and develop methods by which the METOC community can better contribute to these components of Naval operations. Records of class A, B and C afloat mishaps during March 1997 – March 2002 from the Naval Safety Center (NSC) were the primary data source for this study. Our major objectives in analyzing this data were to identify: (1) METOC related mishaps (MRMs); (2) the costs of these mishaps; and (3) the phenomenological and operational conditions under which these mishaps occurred.

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I. INTRODUCTION

A. OVERVIEW OF STUDY

The U.S. Navy operates in hazardous atmospheric and oceanic environments. These hazards can lead to significant losses of lives, health, equipment, and readiness. A number of major losses to the Navy have been the direct results of hazardous METOC phenomena. One of the best-known historical cases is one in which a battle group commanded by Admiral W. Halsey encountered a typhoon near the Philippines in December 1944. The high winds and seas generated by the typhoon directly led to the sinking of three ships, the loss of almost 100 aircraft, and the deaths of nearly 800 men (Morison 1947). During the mishap investigation that followed, Halsey stated that the METOC information available from Fleet Weather Central in Pearl Harbor was not sufficiently specific and timely to allow him to make the appropriate decisions (Saliba 2002). But others maintained that weather reconnaissance and forecasts provided adequate warnings that Halsey failed to heed in time (Bryson 2000, Saliba 2002). Still others have stated that many of the losses could be attributed to poor procedures for dealing with an approaching tropical cyclone (TC) and/or failure to follow appropriate procedures (Morison 1947).

Many improvements have been made since World War II in understanding and forecasting hazardous METOC phenomena, and in developing safer procedures for dealing with these hazards. But the Navy continues to suffer many METOC related mishaps (MRMs). The direct costs of these mishaps are significant and include lost: (1) lives; (2) labor; (3) equipment; and (4) dollars. The indirect costs include: (1) loss of readiness; (2) investigation costs; (3) litigation costs; (4) damage to the fleet's reputation; and (5) damage to the METOC community's reputation

This study is an attempt to identify Naval afloat MRMs, their costs, and the circumstances under which they occurred. The purpose of this study is to identify ways in which the Naval METOC community can better contribute to operational risk assessment, risk management, safety, and readiness. Our hope is that by doing so, the number and the cost of afloat mishaps can be reduced.

B. OVERVIEW OF NAVAL SAFETY POLICIES

When a mishap occurs in the fleet, a mishap investigation is conducted and a report is prepared as part of the Navy's effort to reduce the number and severity of mishaps. The Naval Safety Center (NSC) in Norfolk, VA, oversees the procedures for preparing mishap reports, and for analyzing and archiving them. The goal of the Naval Safety Center (NSC), as stated by Naval Occupational Safety And Health (NAVOSH) Program Manual For Forces Afloat (Dept. of Navy 2001a), is to enhance operational readiness and mission accomplishment by establishing an aggressive safety and occupational health (SOH) program that will reduce occupational injuries, illnesses or deaths, and material loss or damage, and to maintain safe and healthy working conditions for personnel. The safety aspects of the program address the elimination or control of hazards that can result in immediate injury or death. The occupational aspects are primarily concerned with the identification and elimination, where possible, of adverse health effects of hazardous chemicals, physical, and biological agents.

The NSC maintains an afloat mishap database that includes narrative and statistical summaries of all Naval afloat mishaps. The causes of Naval afloat mishaps are documented in mishap investigation reports (MIRs) and mishap reports (MRs). These reports describe the basic circumstances of the mishap (i.e., the who, what, where, when, and why of the mishap), and provide damage assessments and a description of the effectiveness of the measures used to limit further damage after the mishap occurred. The entire mishap investigation effort is focused on preventing future mishaps.

The causes of mishaps are grouped into four categories: material factors, procedural factors, human factors, and design factors. Material factors consider all material failures and malfunctions, including whether the failures or malfunctions occurred because of normal or abnormal means. This category includes failure due to improper repair or normal wear and tear. Material factors are broken down into the following categories: (1) unauthorized; (2) safeties or guards failed; (3) inappropriate for use; (4) installation or repair faulty; (5) condition defective; and (6) normal wear and tear.

Procedural factors consider the possible effects of policies, regulations, operations, and processes from all levels in the chain of command. Factors that are

considered include policies published by higher authorities, such as preventive maintenance schedules (PMS), technical manuals, Naval warfare publications (NWPs), Navy tactical publications (NTPs), U.S. Diving Manual, operational orders (OPORDs), ordnance publications (OPs), the Safe Engineering and Operation of LCAC (SEAOPS) Manual, and the commanding officer's standing orders. Procedural factors are broken down into the following categories: (1) too complex; (2) not available; (3) incorrect.

Human factors (personnel errors) account for human involvement in the events leading up to a mishap, actions taken as the mishap is occurring, and actions taken after the mishap occurred. Human factors are broken down into the following categories: (1) unsafe acts; (2) unsafe supervision; (3) unsafe crew conditions; and (4) organizational influence. Many mishaps reports list personnel error, a type of human factor, as the causal factor.

Design factors consider whether a design defect caused the mishap. Design factors can be broken down into the following categories: (1) hazard to personnel; (2) hazard to equipment; and (3) maintainability.

The afloat safety bible does not explicitly discuss whether METOC phenomena can be considered causal factors in afloat mishaps. However, the afloat policy on this issue may be inferred from Naval aviation safety policy that states that the causes of mishaps are factors over which humans have control (Dept. of Navy 2001b). Therefore, METOC phenomena, which are conditions over which humans have no control (e.g., temperature, sea state, winds), are not considered to be causal factors. However, METOC operations and METOC affected operations may be causal factors. For example, an inadequate weather forecast or improper weather avoidance procedures might be causal factors in a mishap, but the METOC phenomena that occurred prior to or during the mishap (e.g., high winds and seas) would not be causal factors, according to Naval safety policies (Dept. of Navy 2001b).

Although METOC phenomena are not considered causal factors, they can still be regarded as contributing factors. However, in afloat MIRs and MRs the descriptions of METOC phenomena are generally very limited (e.g., a brief narrative statement from the ship's Safety Officer stating simply "high winds and seas"). There is no consistent and

readily identified information in afloat MIRs and MRs that can be used to quickly determine which afloat mishaps were METOC related mishaps. In most MIRs and MRs, even those that involved hazardous METOC phenomena, very little METOC data is provided and little attention is given to how the phenomena might have contributed to a mishap. Even less attention is given to how METOC operations or METOC affected operations might have contributed to the mishap. As a result, for most afloat mishaps, the extent to which METOC phenomena and operations contributed to the mishaps is not immediately apparent from examining the MIRs and MRs.

C. METOC ROLE IN OPERATIONAL RISK MANAGEMENT, SAFETY, AND READINESS

Operational risk management (ORM) is a process used by the Navy to increase the probability of a successful mission by anticipating and managing all the risks involved in that mission. In ORM, people at all levels increase their operational effectiveness by anticipating hazards and identifying and implementing methods for reducing the risk imposed by those hazards. ORM involves a five-step process: (1) identify hazards; (2) assess hazards; (3) make decisions to mitigate hazards; (4) implement risk reduction procedures; (5) supervise risk reduction procedures. METOC related ORM (MRORM) is similar to ORM but with an emphasis on hazardous METOC phenomena, and the development and implementation of appropriate METOC operations and METOC affected operations for mitigating those hazards. Examples of steps in METOC related ORM include identifying and forecasting approaching storms at sea, developing procedures for communicating METOC information to ship drivers, developing procedures for evading storms, and training operators on how to safely operate vessels under adverse METOC conditions. The overall consequences of failing to properly anticipate and prepare for METOC related hazards are shown in Figure 1. This figure illustrates how deficiencies in METOC products and services, in assessing METOC risks, and/or in managing METOC risks can lead to mishaps. Mishaps can then lead to a loss of readiness and thereby make an organization incapable of conducting its mission.

D. REVIEW OF PRIOR STUDIES

This study on the METOC aspects of Naval afloat risk management, safety, and readiness follows a comparable study conducted by Cantu (2001) on the role of weather

in Naval aviation mishaps. The Cantu study is one of only a very few that directly address the METOC aspects of Naval aviation safety (cf. Cantu 2001). As far as we were able to determine, no prior studies of the METOC aspects of afloat safety have been done. Our discussions with a number of people who have been or are involved in military and civilian afloat safety turned up no other studies comparable to this one. These discussions include communications with personnel at NSC (S. Scudder, 2002, personal communication), in the merchant marine industry (M. Diehl, 2002, personal communication), in the Coast Guard (A. Marsilio and D. Venne, 2002, personal communication), at Woods Hole Oceanographic Institute (H. Kite-Powell, 2002, personal communication), in the II Marine Expedition Force Headquarters (R. Nichols, 2002, personal communication), and at Optimum Track Ship Routing, North Atlantic Naval Meteorology and Oceanography Center (NLMOC, P. Dixon and S. Bingham, 2002, personal communication). All of these people stated that they did not know of any prior studies of the METOC aspects of afloat safety.

E. MOTIVATIONS FOR STUDY

Admiral Vern Clark, Chief of Naval Operations, stated in an All Navy message on 26 November 2002 (Clark 2002): "The success of Naval operations is based upon a willingness to balance risk and taking the bold, decisive action necessary to triumph in battle. At the same time, commanders have a fundamental responsibility to safeguard highly valued personnel and material resources, and to accept only the minimal level of risk necessary to accomplish mission." We hope that this study will assist in the Navy's risk management, safety, and readiness efforts. This study was prompted by the Cantu (2001) study, and by an office call with the Oceanographer of the Navy in September 2001 in which the Oceanographer, RADM R. West, stated that he thought an afloat study comparable to LCDR Cantu's needed to be done (R. West, 2001, personal communication).

F. OUTLINE OF THIS STUDY

In this study, we have analyzed NSC mishap records to identify: (1) METOC related mishaps (MRMs); (2) the costs of these mishaps; and (3) the phenomenological and operational conditions under which these mishaps occurred. We define a MRM as a mishap in which one or more of the following occurred:

1. Meteorological and/or oceanographic phenomena significantly increased operational risks. Examples of phenomena include:
    a. high winds or seas
    b. rain
    c. snow and ice
    d. tides and currents.
2. METOC related operational deficiencies increased the risk to operators. Examples of operational deficiencies:
    a. breakdown in METOC related ORM process
    b. lack of real time forecast
    c. lack of MET team and/or brief
    d. breakdown in communication between METOC and Afloat personnel
    e. lack of training, understanding, and/or competence

Our overall goals for this study were to identify methods for: (1) improving METOC related operational risk management; (2) improving safety; (3) increasing fleet readiness; (4) improving METOC products and services for war fighters; and (5) increasing the contributions of the METOC community to the fleet.

The major milestones for this study were:

1. Develop a database of MRMs.
2. Take initial steps for developing risk management, safety, & readiness metrics for METOC community.
3. Develop recommendations for METOC, Afloat, and Safety communities.
4. Develop baseline data set for quantifying future contributions of METOC community.
5. Identify and begin developing METOC related training modules for afloat community.

II. DATA AND METHODS

A. DATA

Our primary data sources were approximately 8000 afloat MIRs and MRs from NSC for the period March 1997 – March 2002. To understand this data, it is important to understand the process the Navy uses in investigating and reporting afloat mishaps.

1. Afloat Safety Bible

The primary afloat mishap document is Navy Occupational Safety and Health (NAVOSH) Program Manual For Forces Afloat (Dept. of Navy 2001a), which is often referred to as the "afloat safety bible." The purpose of this document is to provide commanding officers, safety officers, managers, supervisors, and workers for afloat commands with the guidance and direction necessary to implement the NAVOSH program. In the remainder of this section, several sections of this document are excerpted and discussed in order to clarify the nature of the data sources for this study. In particular, the contents of Tables 1, 2, and 3 are direct quotes from Dept. of Navy (2001a).

Table 1. Ships to Which the Navy Safety Bible Applies

(1) Commissioned, U.S. Navy ships and their embarked equipment, boats, and landing craft, floating dry docks, or leased boats.
(2) Pre-commissioned, U.S. Navy ships and their embarked equipment, boats, and landing craft, or leased boats beginning when the ship gets underway for Acceptance Trials.
(3) USNS ships manned by Federal civilian mariners assigned to ships in the Military Sealift Command (MSC).
(4) All on-duty diving mishaps.

Table 2. Mishaps for Which Shipboard Mishap Investigation And Reporting Procedures Apply

Shipboard reporting procedures apply to those mishaps in which there was:
(1) Damage to the ships and the ships' embarked equipment and craft listed above at all times, both underway and moored.
(2) Death or injury to all personnel (including embarked personnel) aboard ships or craft listed above while underway.
(3) Death or injury to ship's or embarked craft's military and Federal civilian mariner crew members (permanent or under temporary orders) when moored and when on-duty ashore

Table 3. Categories of Reportable Afloat Mishaps

(a) Class A Mishap. Total cost of reportable damage is $1,000,000 or more; or any injury or work-related illness resulting in death or permanent total disability
(b) Class B Mishap. The total cost of reportable property damage is $200,000 or more, but less than $1,000,000; an injury or work-related illness resulting in permanent partial disability; or a mishap resulting in the hospitalization of three or more people.
(c) Class C Mishap. The resulting total cost of reportable property damage is $20,000 or more, but less than $200,000; or an injury or disability preventing personnel from performing regularly scheduled duty for 5 days (1 day for embarked Marines) or more after 2359 on the day of injury or onset of illness.
(d) Afloat Special Case Mishap. The following special case afloat mishaps require the submission of an MR:
1. All cases of electric shock. Include the voltage in the report.
2. All cases of grounding, collision, and flooding.
3. All fires.
4. All cases of hazardous material, chemical or toxic exposure requiring medical attention.
5. All mishaps involving explosives, oxidizers, incendiaries, explosive systems or chemical warfare agents. Mishaps include detonation, accidental launch, malfunction, dangerous defect, improper handling, damage to a launching device, weapon impact off range, or other unusual or unexpected weapons-related occurrence.
6. All diving cases involving central nervous system (CNS) oxygen toxicity, pulmonary over inflation syndrome (POIS) or hyperbaric treatment.
7. All cases of back injury resulting from a mishap requiring medical attention.
8. All cases involving nuclear weapons, nuclear propulsion plants, or radioactive materials involved in these systems. However, mishaps associated with the secondary side of the ship's nuclear propulsion plant or non-nuclear components are reportable.

2. Mishap Investigation and Reporting Procedures

When a Class A, B, or C Naval afloat mishap occurs, the severity of the mishap dictates the investigation and reporting procedure. NSC appoints a trained mishap investigation advisor for all afloat Class A mishaps, and provides an advisor for other mishaps when a trained investigator would be beneficial to the investigation (Dept. of Navy 2001). For Class B and C mishaps, a mishap Report (MR) is used. This type of report provides an assessment as to what caused the mishap (material, human, procedural, and/or design factors). This report is submitted to the Naval Safety Center within 30 days by the command under the following circumstances:

1. Class B mishaps occurring on board ship that are not investigated by an MIB and reported in an MIR.
2. Reportable Class C mishaps occurring on board ship, to the ship's (and embarked unit's and detachment's) on-duty personnel ashore, or involving damage to the ship's equipment located ashore.
3. Afloat special case mishaps occurring on board ship or to the ship's (and embarked units and detachments) on-duty personnel ashore.
4. Class A or B mishaps occurring to the ship's (embarked unit's and detachment's) on-duty personnel while ashore or involving damage to the ship's equipment located ashore.

Commanding officers are encouraged to submit a MR with lessons learned for non-reportable mishaps, near mishaps, or design or material defects that could lead to mishaps.

For Class A mishaps, the reporting procedure is more detailed. The Immediate Superior In Command (ISIC), or other higher authority, appoints a mishap investigation board (MIB) for all afloat Class A mishaps. All MIBs consist of a senior member and at least two additional members. The board's purpose is to investigate the mishap and determine the causes. The board prepares a Mishap Investigation Report (MIR) with its findings, conclusions, and recommendations (Dept. of Navy 2001).

The senior member of the MIB has to be an unrestricted line officer in the U.S. Navy or U.S. Marine Corps, or a senior official in Military Sealift Command (MSC). The senior member should be senior to the commanding officer of the command involved in the mishap. If junior to the commanding officer, the senior member will be from another command. In addition to the senior member, the appointing authority will appoint a minimum of two commissioned officers to the MIB. If a Marine or Marine equipment is involved in the mishap, the appointing authority should appoint a U.S. Marine Corps officer as a member of the MIB. In all cases involving death or injury, the appointing authority includes a medical officer, or medical department representative for LCACs, as an additional member to the MIB.

The ISIC and the commanding officer of the unit involved coordinate the time and location of the initial meeting of the MIB. The ISIC provides the convening date and location to the operational chain of command and NSC as soon as possible. The ISIC or the commanding officer of the unit involved provides the accommodations, local transportation, and administrative support. The senior member of the MIB has the authority to release messages specifically related to the mishap investigation and the MIR.

The MIB conducts its investigation of the mishap separately from all other investigations. Members of the board cannot release information revealing the source of any physical evidence obtained as a result of privileged information (see next section) or any testimony given under the assurance of privilege. Board members are required to cooperate with each other and provide access to non-privileged physical evidence and witnesses.

3. Concept of Privilege

Two important parts of the NAVOSH program (Dept. of Navy 2001) are: (1) the protection of people who fully cooperate with in a mishap investigation from any kind of negative consequences for providing that information; and (2) the concept of privileged information. Individuals providing information to mishap investigators under a promise of confidentiality are advised that the Navy will use its best efforts to ensure that the information is not released to any other agency or individual. The concept of privilege is

that information designated as privileged cannot be used as evidence for disciplinary action, and those participating are assured confidentiality.

The purpose of designating information as privileged is to overcome any reluctance of an individual to reveal complete and candid information about the events surrounding the mishap and to encourage mishap investigators and the endorsers of MIRs to provide complete, open, and forthright information, opinions, causes, and recommendations about a mishap (Dept. of Navy 2001). Information that is voluntarily provided during a mishap investigation under a promise of confidentiality, or information which would not have been discovered but for voluntarily disclosures provided under a promise of confidentiality, is considered privileged information. The analyses of findings, conclusions, and recommendations of the MIB in the MIR are also considered privileged information. Also privileged are calculations and deductions the MIB makes that would reveal the board's deliberative process. Mishaps investigation report endorsements (MIREs) are also part of the deliberative process and are similarly privileged against disclosure (Dept. of Navy 2001). Failure to properly handle or safeguard privileged information can result in disciplinary action.

4. Special Handling Requirements for NSC Data

In obtaining the raw data from the NSC, the author was requested to signed a Statement of Understanding stating that he understood the following:

1. The data/reports I have requested may contain privileged information.
2. Unauthorized disclosure of privileged information by military personnel is a criminal offense under Article 92, Uniform Code of Military Justice.
3. Unauthorized disclosure of privileged information by civilian government personnel will subject them to disciplinary action under Civilian Personnel Instruction 752.
4. No names (commands, ships, or individuals) may be used in my work/product (thesis, paper, study, etc.) if attributed to this data/report.

5. A copy of my final work/product (thesis, paper, study, etc.) will be provided to the Naval Safety Center, Code 30 to be used for safety awareness of the U.S. Navy.

6. I will not release this information to the public or media.

7. All information provided to me will be used only for safety purposes.

8. Further release of this information by me is controlled by OPNAVINST 5100.19D, 2001.

9. If my finished work/product (thesis, paper, study, etc.) is to be published, I will provide a copy to the Naval Safety Center for approval prior to publication.

This study is based on data that falls under the concept of privilege. However, this report has been written in such a way that it contains no privileged information.

5. METOC Information in Afloat and Aviation Mishap Reports

The requirements for reporting METOC phenomena and operations associated with afloat mishaps are very general, and do not specifically require or prompt the reporters to provide detailed METOC information. The afloat safety bible (Dept. of Navy 2001) simply states that weather conditions should be reported (e.g., temperature, relative humidity, visibility, lighting, ventilation, air quality, wind speed, sea state, current, tide, wind direction, precipitation, lightning, ducting, hurricane, and other). In practice, most afloat mishap reports contain only general narrative descriptions, and perhaps a few observations, of METOC phenomena. The afloat safety bible does not require any specific METOC phenomena to be reported. Nor does it require the use of clearly defined METOC terms, or the consistent use of those terms in all afloat mishap reports. Finally, the afloat safety bible does not require that METOC qualified personnel be involved in the investigation or reporting of mishaps, even mishaps that clearly involve METOC phenomena, METOC operations, and/or METOC affected operations.

This study was prompted in part by Cantu's (2001) analyses of Naval aviation mishap records. We anticipated being able to conduct similar analyses, but were surprised to find that the requirements for reporting METOC phenomena and operations

are much more lax for Naval afloat mishaps than for Naval aviation mishaps. When an aviation mishap occurs, many details of the associated METOC phenomena, METOC operations, and METOC affected operations are reported (e.g., quantitative observations of winds, clouds, visibility; specifics about the METOC forecast and briefs provided to the operators; details about how the operators prepared for the briefed METOC conditions. The reporting forms used in the investigation of aviation mishaps prompt the reporter to provide information on many METOC aspects of the mishaps, including METOC phenomena, METOC operations, and METOC affected operations (Figures 2 and 3). This detailed information allows more detailed analyses to be conducted of the METOC aspects of aviation mishaps than of afloat mishaps (cf. Cantu 2001).

B. METHODS

1. Selection of Study Period and Basic Analysis Procedures

When we began this study in summer 2001, afloat mishap records were available only in hard copy form for mishaps that occurred prior to March 1997. We chose to conduct our study for the period for which NSC was able to provide records in electronic format, March 1997 – March 2002. During this period, there were approximately 8000 afloat mishaps. The lack of detailed and consistently used terms for reporting METOC phenomena, METOC operations, and METOC affected operations made it difficult to sort the reports using word searches or similar methods. So each report was read one at a time to determine if the mishap was METOC related.

The METOC phenomena that were described in the MRs and MIRs were generally described with a few words (e.g., high seas, high seas and high winds, fog, etc.). The most commonly used descriptions of METOC phenomena are listed below. These descriptions are grouped into the seven categories that we used to sort the mishaps according to the METOC phenomena with which they were associated.

1. High Winds and Seas
    a. High Seas
    b. High Seas and High Winds
    c. High Seas, High Winds, and Rain

2. High Winds

3. Rain

   a. Rain

   b. Thunderstorms

   c. Mist

   d. Humidity

   e. Drizzle

   f. High Winds, Rain, and Snow

4. Ice and Snow

   a. Ice

   b. Snow

   c. Ice and snow

5. Tropical Cyclone

6. Tide

7. Fog

2. Identification of METOC Related Mishaps (MRMs)

I analyzed all afloat mishaps during the study period (March 1997 – March 2002) to identify those that were METOC related mishaps (MRMs). In a MRM, METOC phenomena, and/or problems in METOC operations or METOC affected operations, contributed to the mishap. Examples of mishaps in which METOC phenomena contributed to a mishap include those in which METOC conditions (e.g., high winds or heavy seas) directly and significantly increased the hazards to operators and/or equipment.

Examples of problems in METOC operations that contributed to a mishap include those in which there was a:

1. breakdown in METOC related ORM process
2. lack of training, understanding, and/or competence
3. lack of real time forecast
4. lack of MET team and/or brief
5. breakdown in communications between METOC and Afloat personnel

Problems in METOC affected operations that contributed to the MRMs include procedural and human factors. The human factors can be broken down into the following categories and examples:

1. Unsafe acts (e.g., operator acted without properly accounting for METOC phenomena)
2. Unsafe supervision (e.g., supervisor did not ensure proper training and/or did not properly review conduct of operator)
3. Unsafe crew conditions (e.g., overloading a small boat for the given sea state)
4. Organizational influence (e.g., perceived urgency of evolution led organization to proceed without getting appropriate input to the ORM process from METOC personnel)

Here is an example of a MRM in which METOC related human factors were the primary cause of the mishap. Heavy seas were forecast for an amphibious exercise. The exercise commander set the course and speed for one of the ships in a manner that did not allow one of the ships to make adjustments in a timely manner to achieve the best ride. The ship took severe rolls due to the high seas, and equipment broke loose and caused injuries and damage. In this case, the heavy seas were forecast, but the operators and their supervisors failed to properly prepare for them by allowing timely adjustments in the ship's course and speed. The operators also failed to properly manage the METOC risks by rigging the ship for the heavy seas in accordance with its heavy weather bill. The concept of heavy weather, and the basic procedures to be followed in order to

manage heavy weather risks, are discussed in Dept. of Navy (2001a, chapter C16) and in Table 4.

Table 4. Heavy Weather, From Dept. of Navy (2001a)

CHAPTER C16
HEAVY WEATHER

C1601. DISCUSSION

a. Heavy weather is any weather condition that results in high winds, extreme sea states, and heavy rain, snow and/or hail.
b. There are multitudes of hazards present in heavy weather. Objects can slide or fall on personnel, causing injury. Personnel can fall into machinery or equipment. All personnel must be aware of potential hazards and safety requirements.

C1602. LIFELINES

a. Keep lifelines or rails rigged at all times along all boundaries. Keep permanent lifelines in good repair.
b. Keep unguarded openings adjacent life rail or lifeline sections or an end section and adjacent structures to a minimum and in no case greater than 5 inches.

C1603. TIE-DOWNS

a. Use approved tie-downs or lashing to secure moveable shipboard items, such as aircraft, vehicles and cargo, against the motion of the ship and exposed areas against the forces of wind and waves.
b. Seize or tie-down shackles, hooks, turnbuckles, release devices to prevent working loose. Check them for security more frequently in heavy weather.

C1604. SAFETY PRECAUTIONS UNDER HEAVY WEATHER CONDITIONS

a. Be aware of stowage locations of all equipment necessary for rigging heavy weather lifelines.
b. Inspect tie-down equipment such as cables, turnbuckles, deck pads and bolts, at frequent intervals to ensure their security.
c. Only use the fittings provided on the aircraft, vehicle, and equipment to be transported to secure the item to the ship.
d. Do not use excessive force to place a tie-down onto a fitting.
e. Ensure that the arrangement of individual tie-down assemblies is in strict conformance with design requirements.
f. Ensure that when lashing and tie-down equipment is not in use, it is stowed in its proper location.

Enclosure (1)

The determination of which MIRs and MRs were MRMs was based on what we call the *Practical Man Test* (PMT, Figure 4). In the PMT, three main questions were asked:

1. Would the mishap have happened in a benign environment?

2. Would the mishap have happened if an accurate METOC forecast and brief had been provided at the proper stage in the ORM process?

3. Would the mishap have happened if appropriate procedures for dealing with METOC phenomena had been followed?

If the answer to question 1 was "no", the mishap was considered to be a MRM. If the answer to question 1 was "yes" or "maybe", question 2 was asked. If the answer to question 2 was "no", the mishap was considered to be a MRM. If the answer to question 2 was "yes" or "maybe", question 3 was asked. If the answer to question 3 was "yes" or "maybe", then the mishap was considered to not be a MRM.The answers to the PMT questions were made by the author and were based on his Naval experience as: (1) a qualified Surface Warfare Officer (SWO), qualified both topside and in engineering; (2) a qualified METOC Officer; and (3) a Qualified Afloat Safety Officer. For mishaps in which the answers to the PMT questions were not clear, other Naval officers with comparable qualifications were asked for second opinions.

The application of the PMT to the full set of afloat MIRs and MRs led initially to the identification of 263 MRMs. These 263 mishaps were then examined a second time. This examination was conducted with the assistance of other qualified Surface Warfare and METOC officers to make the final determination of whether a mishap was a MRM or not (see Acknowledgments). After these analyses, the total number of MRMs was reduced to 166, or roughly 2 percent of the total set of 8000 MIRs and MRs. However this 2 percent is a misleading number, as is explained in the following paragraph.

Most of the MIRs and MRs contained little information about METOC phenomena, METOC operations, and/or METOC affected operations. Much of the information that was provided was vague and non-quantitative. This lack of information made it impossible for most mishaps to determine whether or not they were METOC related. Thus, we were not able to determine the actual percentage of mishaps that were MRMs. Similar problems occurred in the reporting of damages and injuries. Many of the MIRs and MRs contained too little information to accurately determine the costs of equipment damage or the extent of personal injuries. Thus, we were not able to

determine the true costs of the mishaps, and in particular the MRMs. These problems with missing data are discussed further in Chapter IV.

3. Development of METOC Related Mishap Database

A database containing the specifics of all the MRMs was constructed using Microsoft Access as the platform. The database was set up to incorporate as much information from the MRs and MIRs as possible. The following is a list of the database fields:

1. Day
2. Time
3. Month
4. Year
5. Mishap Date
6. Mishap Time
7. Ship Hull Number
8. Unit Identification Code
9. Evolution At Time Of Mishap
10. Mishap type
11. Mishap Class
12. On/Off Duty
13. On/Off Ship
14. Human Error
15. Human Error Type
16. Would Have Happened Without Element
17. Personnel Type
18. Lost Days of Work
19. Light Duty Days

20. Disability
21. Equipment Damaged
22. Equipment Type
23. Equipment Cost
24. Environmental Element
25. Tropical Cyclone data
26. Forecast Available
27. Brief Given
28. Forecast Believed
29. Disseminated
30. Risk Assessed
31 Risk Assessment Believed
32. Missing Input From MIR
33. Comment Box

Once this database for the 166 MRMs was completed, we were able to conduct a number of analyses (e.g., to identify and analyze the circumstances of the MRMs that were associated with a tropical cyclone). Some of these analyses required the use of additional information; for example, the use of best track TC data from the Joint Typhoon Warning Center (JTWC) and the National Hurricane Center (NHC). The results of these analyses are presented and discussed in chapter 3.

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III. RESULTS

A. OVERVIEW

We identified 166 Class A, B, and C afloat MRMs during our 5-year study period (March 1997 March 2002). This compares to 11% of the Class A aviation mishaps found by Cantu (2001). Figure 5 shows the breakdown of the afloat MRMs by mishap class. Most of the MRMs were Class C mishaps.

B. COSTS OF MRMS

The costs of the 166 MRMs were significant (Figures 6 – 11). A total of 7 crewmembers were killed during the 5-years, for an average of 1.5 deaths per year (Fig 6). There were 132 MRMs (80% of the total number of MRMs) that led to personal injuries (Figure 7). Most of these were Class C mishaps.

There were 79 MRMs that involved equipment damage. The cost of this damage over the 5 years was approximately $9 million. This represents 79 MRMs at an average cost of $54,200 per event. Figure 8 shows the average MRM damage cost for each mishap class.

There was a total number of 2,707 lost work days during the study period for all classes of MRMs (Figure 9), for an average of 540 lost duty days per year. The average MRM led to 16 days of lost duty. The 166 MRMs led to 1,757 light duty days (Figure 10), for an average of 350 light duty days per year. The average MRM led to 11 days of light duty. Thus, the average MRM during the study period led to: (1) 26 days of light or lost duty; and (2) 2.5 people per day on light or lost duty status.

This summary of the personal injury costs does not fully account for all the lost and light duty days, since a number of the MIRs and MRs were filed before the full costs had accrued. This summary also does not account for the costs of medical care, wages paid to people who were unable to perform their duties, and other costs that are not documented in the MIRs and MRs.

C. OPERATIONS, VESSELS, AND PERSONNEL INVOLVED IN MRMS

The MRMs were categorized according to the type of operation (type of evolution) that was being conducted when the mishap occurred. The four operation

categories are: (1) underway, (2) moored, (3) privately owned vehicle (POVs), and (4) liberty. Because of limited or missing input data in the MIRs and MRs, the underway category could not be into sub-categories, such as replenishment or formation steaming. Moored is defined as any time the ship is secured in a berth or at anchor. The POV category describes situations in which a crewmember was operating a personal vehicle while on duty or while in transit to or from work. Liberty is defined as any time a crewmember is off duty and free to pursue personal activities.

Figure 12 shows the number of MRMs per operation types. Most (70%) of the MRMs involved shipboard operations, with underway operations having 83 MRMs and moored accounting for 34 MRMs. 41 (25%) of the MRMs involved POV operations. The underway and moored MRMs involved almost every type of vessel in the U.S. Navy (Figure 13), with carriers accounting for the most MRMs, 34. Carriers also accounted for the largest number of MRMs with personal injuries, 25, and equipment costs of $3,700,000 (not shown).

The numbers in Figure 13 include MRMs involving small boats that were associated with the types of ships listed in Figure 13. Figure 14 shows that small boat MRMs accounted for 13 or 8% of all MRMs. 10 of these 13 mishaps involved rigid hull inflatable boats (RHIBs). These boats are relatively lightweight, have shallow keels and a shallow draft, and are capable of high speeds and tight maneuvers. Figure 15 shows some of the costs of small boat MRMs. Small boat lost duty days accounted for 14% of the total number of MRM lost duty days, and 22 % of the MRM total of light duty days. Small boat MRMs led to total of 750 lost and light duty days, or an average of 150 lost or light duty days per year. Thus, small boat MRMs account for a disproportionate number of lost and light duty days, indicating that these types of mishaps are especially dangerous. These results also suggest that there are significant shortcomings in the METOC related ORM process for small boat operations (e.g., shortcomings in training and briefing for small boat operations under adverse METOC conditions).

Most of the MRMs (70%) occurred while the personnel involved were on-duty (not shown). The costs associated with POV operations were high. POV MRMs led to 3

deaths, 257 lost duty days, 429 light duty days, and 15% of the total number of lost and light duty days (Figure 16).

28, or 17%, of the MRMs involved officers and 135 or 82% involved enlisted personnel. These proportions are roughly similar to the proportions of total officers and enlisted personnel in the Navy.

D. LOCATION AND TIME OF MRMS

The authors of MIRs and MRs are requested to provide the geographic location (e.g., latitude and longitude, or port). The locations of the MRMs are shown in Figure 17. The greatest concentration of MRMs was along the east coast of the U.S. where a great deal of afloat Naval activity occurs, and where severe storms (e.g., midlatitude cyclones in the winter, tropical cyclones in the summer) are common. Figure 17 also shows concentrations of MRMs in other areas of high Naval activity, including: the west and Gulf of Mexico coasts of the U.S., the Mediterranean Sea, the western Pacific, and the Arabian Gulf. Note from Figure 17 that 5 MRMs could not be located due to incomplete information in the mishap records. Similar geographic clustering of the MRMs is found when the MRM locations are plotted according to mishap class and type of operation (not shown).

The local times at which MRMs occurred were about evenly split between day and night times (55% during the day and 45% at night; not shown). This may indicate that Naval personnel tend to be most active during the day, but that low light levels at night create more hazardous conditions. Most (71%) of the MRMs occurred during the northern winter and spring (not shown). This may be a result of high winter storm activity, and snowy and icy conditions, in the regions where the Navy is most active.

E. METOC PHENOMENA ASSOCIATED WITH MRMS

According to the information about METOC phenomena provided in the MIRs and MRs, 76 (46%) of the MRMs involved high winds and/or high seas (Fig 18). Rain was involved in 61 (37%) of the MRMs. Other types of phenomena were involved in the MRMs to a much smaller extent. It is important to keep in mind however, that the MIRs and MRs provide only very limited information about phenomena. Nonetheless, the results shown in Figure 18 raise the following questions for the METOC community. Is accurate METOC information about high wind and sea conditions being properly

communicated to afloat users? If it is, is the information not being understood? If it is being understood, is there a breakdown in the ORM process for dealing with high winds, seas, and rain?

The MIRs and MRs indicated that only 5 afloat mishaps during the study period involved tropical cyclones (TCs). However, since many of the MIRs and MRs gave only limited information about METOC phenomena, we conducted a more in depth analysis of all 166 MRMs to identify all that were TC related. We did this by comparing the locations and times of the mishaps with TC best track data from JTWC (for the western Pacific and Indian Ocean basins) and NHC (for the North Atlantic and eastern North Pacific basins). This analysis revealed that a total of 15, or 9%, of the 166 MRMs were TC related (Figure 19). 8 of these occurred in the North Atlantic, where Naval activity is high, and 5 occurred in the western North Pacific, where TC activity is high and Naval activity is relatively high (McBride 1995). Two of the TC related MRMs that occurred in the North Atlantic during 1999 were associated with one TC, Hurricane Floyd, which moved poleward along the east coast of the U.S. during September 1999. The MIRs and MRs did not provide evidence of any TC related MRMs in the Indian or eastern North Pacific basins. Figure 20 shows the total number of TC related mishaps per year. Note the overall declining trend, from 6 TC related mishaps in 1997 to zero in 2001. This trend may be an indication of the improvements in TC track forecasting for both the western Pacific and North Atlantic basins (Jeffries and Fukada 2002; M. Boothe, 2002, personal communication). Additional analyses of TC related mishaps prior to and after our study period could help clarify the changes in TC related mishaps and provide a measure (i.e., a metric) of METOC contributions to afloat operations. Such studies should be designed to determine and compare the year-to-year variations in TC activity, Naval afloat activity, and TC track forecasting skill.

F. METOC OPERATIONS AND METOC AFFECTED OPERATIONS ASSOCIATED WITH MRMS

One of the objectives of our study was to determine to what extent afloat mishaps were associated with: (1) adverse METOC phenomena; (2) deficiencies in METOC operations; and/or (3) deficiencies in METOC affected operations. The occurrence of

either of the two operational deficiencies would indicate a breakdown in the ORM process used to assess and manage METOC hazards.

We determined that 123, or 74%, of the 166 MRMs would not have happened in a benign environment (Figure 21). Thus, in these mishaps, we concluded that adverse METOC phenomena were primary contributors to the mishap. We also concluded that 26% of the MRMs occurred without METOC phenomena making a primary contribution. In these mishaps, operational problems were the primary contributor to the mishap, with METOC phenomena not being involved or making a secondary contribution to the mishap. In many of these cases, METOC operations and/or METOC affected operations led to the mishap, but the mishap was exacerbated by adverse METOC conditions. An example of such a mishap is given in the following paragraph.

During a mooring evolution, a ship had too much speed for the current and struck the pier. This mishap would have happened without any current, due to the ship's excessive speed. However, the presence of the current increased the damage. This mishap was mainly due to two operational problems: (1) lack of appropriate METOC forecast and brief; and (2) failure to follow appropriate procedures for the METOC conditions. Problem 2 is an example of a deficiency in METOC operations and indicates a failure in the METOC related ORM process. Problem 2 is an example of a deficiency in METOC affected operations. Thus, the primary causes of this mishap were operational, not phenomenological.

Figure 22 shows the number of MRMs for which a METOC forecast was provided for the operation in which the mishap occurred. For 33 of the MRMs, it was clear whether a forecast had been provided (25 MRMs had a forecast, 8 did not). The lack of METOC information in the MIRs and MRs prevented the author from determining whether a forecast was provided for the vast majority of the MRMs (133 out of 166). These determinations were based in part on the documentation provided in the MIRs, and in part on the author's Naval experience and qualifications (see chapter 2).

We also investigated whether a METOC brief was provided for the operations in which a MRM occurred. The answers to this question are shown in Figure 23. As with

the METOC forecast issue (Figure 22), in most cases it was unclear whether a brief had been provided to the operators.

For only 20 of the MRMs were we able to determine that the operators followed appropriate procedures for dealing with the METOC conditions under which they were operating (Figure 24). Of the 166 MRMs, 139, or 84%, involved some sort of deficiency in training on how to assess, manage, and/or operate in adverse METOC phenomena (Figure 25). Examples of these deficiencies include: lack of training in determining wave heights; inadequate supervision of personnel who are going to be operating in adverse METOC conditions; and lack of training on how to operate a small boat in high seas.

The lack of information in afloat MIRs and MRs about forecasts and briefs is in sharp contrast to the case for aviation MIRs and MRs (cf. Cantu 2001). This, of course, makes it much more difficult to identify for afloat mishaps what METOC operational deficiencies existed, and how METOC products and services could be improved in the future. However, for certain types of mishaps, supplemental information may be used to assess value of METOC products and services. For example, the use of supplemental information about TC activity and TC forecasts may be used to clarify the METOC aspects of TC related mishaps. Also, the use of optimal track ship routing (OTSR) information may be used to supplement mishap records and provide a better description of the value of METOC products and services, as shown by Hinz (2002).

G. CASE STUDIES

In this section, we present four case studies that illustrate the various ways in which problems in METOC related ORM can lead to mishaps and a loss of readiness (see Figure 1). These cases also provide specific examples of lessons for the METOC community on how to better contribute to afloat operations. One of the benefits of case studies is that they can help clarify the overall operational context in which MRMs occur.

1. Case 1

A moored carrier was preparing to conduct morning colors. Ongoing deck work caused the color guard to proceed to the carrier's island structure to raise the flag from the ship's main mast. While raising the flag, a wind gust exceeding 25 knots ripped the lanyard and flag from the crewmember's hands. The lanyard & flag became entangled in

a rotating radar antenna. The results were $300,000 in equipment damage and a carrier that was unable to go to sea for 6 days.

The main recommendations from the mishap report were:

a. Conduct coordinated risk assessment & management (ORM) on hazards associated with raising the flag at alternate locations.

b. Develop METOC guidelines for raising flag at alternate locations.

c. Contact METOC office for METOC conditions and account for them when selecting flag size & location.

d. Conduct training.

This mishap report left many important questions, including:

a. Did the Command Duty Officer know of the alternate location and METOC conditions?

b. Was the Officer of the Deck provided with a weather report or brief?

c. Was the color guard given a weather brief?

d. Did the METOC office provide reports or briefs for these kinds of evolutions?

e. What were the overall METOC conditions?

This case shows how something as simple as raising a flag coupled with a hazardous METOC phenomena can grow into a major mishap. METOC related training and METOC related ORM were clearly deficient in this case. As with many other mishap messages, this case was under reported. The absence of critical information for developing improved ORM makes it difficult to learn and disseminate lessons based on this mishap. The results of this MRM indicate, as many do, that the reports and recommendations from MRMs should be developed in conjunction with METOC personnel.

2. Case 2

A guided missile cruiser was independent steaming in the Mediterranean Sea. The ship requested OTSR in its Movement Report (MOVREP). The ship encountered a

winter storm with winds of 50 - 65 kts, seas 12 – 18 ft, low visibility, heavy precipitation, and lightning. Poor weather conditions caused extensive equipment damage and prevented the ship from entering port on schedule. The ship stated that weather information was not available in a timely manner. The result was $30,000 in equipment damage. The mishap report authors recommended that:

a. The ship should have rigged for heavy weather.

b. The ship should have reviewed it's heavy weather bill and planned for unexpected severe weather.

c. Up-to-date and tailored weather information should be available in the Mediterranean.

d. The ship should ensure that its long-range training plan general military training (GMT) cover heavy weather rigging, storm avoidance, and meteorological products & procedures.

The mishap report provide no indication of:

a. What METOC products if any were used by the navigator to plan the ship's course through the storm.

b. Whether the ship received a warning and forecast from METOC Rota via MRSAT call or JOTS OPNOTE.

c. What pre-deployment training on heavy weather operations & METOC product availability were provided to the ship's company.

d. The initial report did not indicate that METOC Rota informed the ship that OTSR was unavailable for the Med.

This case clearly illustrates a breakdown in communication between the METOC community and its customers aboard the ship, especially about what METOC products and services were available for the Mediterranean.

3. Case 3

A guided missile cruiser was independent steaming during a tropical cyclone evasion. Heavy seas from the tropical cyclone causes a pallet truck to break free from its

stowage position allowing it to roll freely back and forth, causing equipment and structural damage. This ship's force proceeded to secure the pallet truck with the overhead chain fall to the battery lifting bar on top of the pallet truck. The ship experience a severe roll, causing the bar to break free and strike one of the crewmembers in the head, knocking him unconscious. The result was a head injury that caused 7 lost work days and $5000 in equipment damage. The mishap report contained no recommendations for avoiding this type of mishap in the future.

This mishap report left out many pieces of information that are vital in evaluating the METOC aspects of the mishap, including:

a. Did the ship receive a METOC forecast and/or brief?

b. Was the ship rigged for heavy weather?

c. Was the ship on the right course for the best ride?

d. Did the ship follow its heavy weather bill?

4. Case 4

While conducting maritime boarding operations in the Arabian Gulf, a ship's RHIB was positioned alongside a merchant vessel. The RHIB was taking on water from heavy seas and water flowing off the deck of the merchant vessel. The RHIB coxswain was maintaining position, when the RHIB was caught by a large oncoming wave and lifted up into the face of the wave. Water that had collected in the RHIB rushed back toward the stern. The free surface effect of the rushing water combined with the force of the oncoming wave caused the RHIB to capsize. The result was $15,000 in equipment damage and 40 operating days lost.

The main recommendations from the mishap report were:

a. Training in adverse weather conditions and varying sea states will help enable boat crew to better compensate for difficult boating maneuvers.

b. Real world missions often require operating in less than ideal conditions. Proper qualifications are of utmost importance, and the fact that all personnel involved were PQS qualified and had trained to this mission, doubtless played a significant role in preventing injury and/or loss of life.

The report for this mishap also left out important information for evaluating METOC issues, including answers to these questions:

a. Did the ship receive a METOC forecast and/or brief?

b. Did the RHIB crew receive a METOC brief prior to the evolution?

c. Did the ship request the merchant vessel to steer into the best seas for best ride?

The major conclusions that can be drawn from these case studies are representative of those found in many of the MRMs. These include the following.

a. Seemingly minor phenomena can have major negative consequences.

b. METOC information needs to brought into ORM early and used throughout the ORM process.

c. Training on how to conduct METOC affected operations under adverse METOC conditions appears to be deficient for many types of METOC phenomena and many evolutions.

d. Mishap reports leave out a great deal of information, especially information about: (1) the specific evolutions being conducted during the mishap; (2) METOC phenomena and operations; and (3) how the ORM process for the evolution was affected by METOC information (e.g., by a forecast or brief).

e. The recommendations and lessons to be learned from mishaps need to be developed in conjunction with METOC personnel.

These and many other cases also provide several specific lessons for the METOC community, in particular:

a. Be sure METOC customers are aware of and understand what METOC products and services are available for their operational areas and evolutions.

b. Know the customers' missions and limitations. Take the initiative and anticipate their needs.

c. Solicit more complete feedback from customers involved in MRMs.

d. Establish a routine process for using mishap reports as a tool for identifying customers' needs.

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IV. SUMMARY AND RECOMMENDATIONS

A. SUMMARY OF PROCEDURES AND RESULTS

In this study, we used Naval afloat mishap reports to identify MRMs, the METOC phenomena that occurred during the mishaps, and the operational conditions under which the mishaps occurred. 8000 afloat MIRs and MRs from March 1997 – March 2002 were reviewed. Most contained relatively little METOC information, even in very well written afloat MRs and MIRs, and even for mishaps that were clearly METOC related. 37 or 22% of the 166 MRs provided less than the minimal amount of required METOC information. Most reports that provided the minimum METOC information still did not provide enough to fully analyze the METOC phenomena or METOC related operation. Thus, it was difficult to determine the complete circumstances of the mishaps and their full costs.

Our major findings for the MRMs we identified during the study period are listed below:

1. We were able to determine that 166 mishaps were MRMs. For most mishaps, there was too little METOC information to determine whether or not they were MRMs.
2. The MRMs caused 7 deaths.
3. The MRMs caused $9,000,000 in equipment damage.
4. The MRMs led to 2707 lost work days.
5. The MRMs led to 1757 light duty work days.
6. Shipboard operations accounted for 70% of MRMs.
7. 25% of the MRMs involved POVs.
8. POVs account for 15% of lost or light duty days.
9. Carriers were involved in more MRMs than any other vessel type, and accounted for 15% of the total MRM personal injuries.

10. MRMs during small boat operations accounted for 8% of all MRMs, 14% of the MRM lost duty days, 22% of the MRM light duty days.

11. Small boat MRMs had a very high labor cost: over 750 days of lost or light duty.

12. 70% of all MRMs occurred while on duty.

13. 81% of the MRMs involved enlisted personnel.

14. 55% of MRMs occurred during the daytime.

15. 71% of the MRMs occurred in the winter and spring months.

16. Major phenomena: high wind and seas accounted for 46% of the MRMs.

17. Rain accounted for 37% of POV mishaps.

18. 9% of the MRMs were tropical cyclone related.

19. In 74% of the MRMs, METOC phenomena were a primary contributor.

20. For 80% of the MRMs, it was not known if a METOC forecast was provided to the operators.

21. For 86% of the MRMs, we were not able to determine if a METOC brief was provided to the operators.

22. For 88% of the MRMs, we were not able to determine if the operators followed appropriate procedures for dealing with the METOC phenomena.

23. 84% of all MRMs involve some type of training issue.

24. 22% of the 166 MRs provided less than the minimal amount of METOC information.

Our findings indicate that Naval Safety Center's MIRs and MRs can be a valuable tool in developing METOC metrics, but more complete mishap records would be much more useful to both the Afloat and METOC communities.

B. CHALLENGES

The system for reporting afloat mishaps, and the lack of clear information about METOC phenomena, METOC operations, and METOC affected operations, presented

many challenges during this study. We found that many afloat mishaps are under-reported. That is, the reports on these mishaps do not give a full accounting of the nature of the mishaps or their true costs. Based on the author's Naval experience and discussions with other officers with similar experience, it appears that under-reporting is done in order to:

1. Understate the true costs (e.g., in personnel injury, equipment damage, lost labor, lost dollars, etc.)
2. Minimize or diffuse responsibility for the mishaps.
3. Protect careers.

It also appears that some mishaps go unreported (i.e., not reported all). It also appears that the true costs of under-reported or unreported mishaps may sometimes be hidden within general operating expenses.

Many of these under-reporting and non-reporting problems may be linked to the culture of the surface Navy. The U.S. Navy surface culture is steeped in a rich history that dates back to John Paul Jones (1747-1792), who stated, "It seems to be a truth, inflexible and inexorable, that he who will not risk cannot win." The surface culture today still holds these words true. This leads to a surface culture in which people:

1. are reluctant to say no to taking on risks
2. try to accomplish more with the same or fewer resources
3. try to accomplish missions in spite of high costs and big risks
4. are inclined to stick with the old ways of doing business because that's the way it's always been done
5. accept losses as simply the cost of doing business

Understanding this culture will help the METOC community understand what the core values of its afloat customers are. This, in turn should help the METOC community identify its own core values and determine how best to proceed in providing METOC products and services to the afloat community.

C. RECOMMENDATIONS

Based on the results of this study, we have developed a number of specific recommendations for the METOC, afloat, and safety communities regarding the METOC aspects of afloat risk management, safety, and readiness.

1. Improve METOC products and services so that they:

   a. better meet customer needs and constraints (e.g., make WEAX messages easier to read and understand)

   b. are more operation specific

   c. provide information critical for ORM

2. Improve education and training for METOC and the fleet on assessing and managing METOC risks (METOC ORM). This includes improving and developing new training modules on how to operate under adverse METOC conditions. See below for a training module that has resulted from this study for teaching small boat operators how to assess and manage METOC risks (Martin and Murphree 2002). The United Kingdom's Royal Naval School of Seamanship may be provide some good models for integrating METOC information into training methods and materials for both the METOC and the afloat communities (see: http://royal-navy.mod.uk/rn).

3. Modify mishap investigation reporting to include increased METOC information & other information that would help METOC community improve its products & services (e.g., more information about ORM, evolution, training, etc.). Mishap reporting by aviation community may be a good model to follow. See below for the METOC information that we will recommend to NSC be included in future afloat mishap MIRs and MRs.

4. Detail METOC officer to work with NSC staff on identification and analysis of METOC related reports.

5. Identify METOC related mishaps as soon as possible so the METOC community can enter them into the MRM database along with relevant METOC data (e.g., METOC analyzed fields, forecasts, and briefs for the mishaps).

6. Have FNMOC and other METOC regional center archive METOC fields for time and place of MRMs.

7. Disseminate the MRM database to METOC and afloat communities for additional analyses.

D. TRAINING

A training module for RHIB operators, Martin and Murphree (2002) has been developed as a by-product of this study. This module provides instruction on assessing and managing METOC risks when planning and conducting RHIB operations under various sea states. The module is a quick, hands-on guide for estimating seas and identifying parameters for safe operations. This product should be especially useful when METOC information from a mobile-team or OA Division is not available. This module will be delivered to the fleet through the Surface Warfare Officer School (SWOS) Department Head Training Program in Newport, RI. The United Kingdom's Royal Naval School of Seamanship may be provide some good models for integrating METOC information into training methods and materials for both the METOC and the afloat communities (Moys 2002, Royal Navy 2002).

E. RECOMMENDATIONS TO NSC

We have recommended to NSC that the following items of information, and answers to the following questions, be included in future afloat MIRs and MRs.

What were the METOC conditions immediately prior to and during the mishap? Please provide quantitative information about: true and relative wind direction and speed, visibility, current, tide, temperature, and sea state category.

In the opinion of the mishap report author, did METOC phenomena or METOC related operations contribute to the mishap? If so, were they primary or secondary contributors?

1. What type of METOC products and services did the ship receive?
2. What was the source of the ship's METOC products and services?
3. Was a METOC forecast provided?
4. Was a METOC brief provided?
5. Were the forecast and/or brief understood?
6. Was the METOC information disseminated properly?
7. What METCO related ORM was conducted prior, during, and after the mishap?
8. What evolution as occurring immediately before and during the mishap?
9. What were the vessel's limits, and did it exceed its limits?
10. What training was received by, and what was the experience of, operators in dealing with the METOC conditions that existed immediately prior to and during the mishap?

F. ACCOMPLISHMENTS

The major accomplishments of this study are: (1) the development of a database of METOC related mishaps used in this and an OTSR study (Hinz 2002) and useful for future studies; (2) the development of recommendations for the METOC, Afloat, and Safety communities; (3) the development of a baseline data set for quantifying future contributions of METOC community to Naval afloat risk management, safety, and readiness; and (4) the identification of the need for, and the development of, a METOC related training module for the Afloat community (Martin 2002).

G. FUTURE WORK

As in many studies like this one, we have perhaps come up with more questions than we have answered. To address these questions, we recommend that the following projects be pursued in future work.

1. Work with CDR Doug Marble, FNMOC, on applying search and rescue (SAR) display system to METOC impacts on ship handling.

2. Develop metrics to quantify hours lost/saved and the dollars lost/saved due to METOC phenomena and operations.

3. Identify how improvements in TC forecasting may have saved lives and dollars.

4. Disseminate the results of this study, for example through METOC, Safety, and other publications (e.g., CNMOC News, Fathom, Naval Institute Proceedings).

5. Examine aviation mishaps using methods developed in this study (e.g., PMT).

6. Do aviation and afloat studies comparable to this one based on:

    a. OTSR records & reports

    b. Post-deployment reports

    c. Lessons learned reports

7. Relate METOC phenomena to specific afloat operations and vessels. For example, answer the following questions:

    a. How many deaths and injuries were associated with each METOC phenomenon?

    b. What phenomena were associated with what operations types? For each operation type, what were the most problematic phenomena?

    c. What phenomena were associated with what vessel types?

    d. For each vessel type, what were the most problematic phenomena?

    e. How much equipment damage was associated with each phenomenon?

8. Relate specific METOC phenomena and operations to specific types of mishap and/or equipment damage that occurred in the MRMs. For example, relate METOC phenomena and operations to:

    a sinkings

b. groundings

c. collisions

d. capsizings

e. equipment damaged after breaking loose for hold downs

f. cable parting

g. fouling

h. entanglement

9. Identify and analyze the METOC operations involved in the MRMs. For example, determine how many MRMs were associated with:

   a. problems with including METOC in ORM

   b. forecasting deficiencies

   c. briefing deficiencies

   d. training deficiencies

   e. problems with adhering to METOC related SOP

10. Calculate mishaps rates. Examples: calculate mishaps per crew members per vessel type

11. Analyze more thoroughly costs associated with personal injuries

   a. account for pay rates of injured personnel.

   b. determine if Officer or Enlisted are disproportionately injured.

12. As more detailed mishap reports become available, analyze the METOC phenomena and operations associated with specific underway operation types – for example:

   a. open ocean transit

   b. port or harbor entry/exit

   c. underway replenishment

d. small boat operations

e. amphibious operations

f. special operation

g. boarding, search and seizure

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APPENDIX. FIGURES

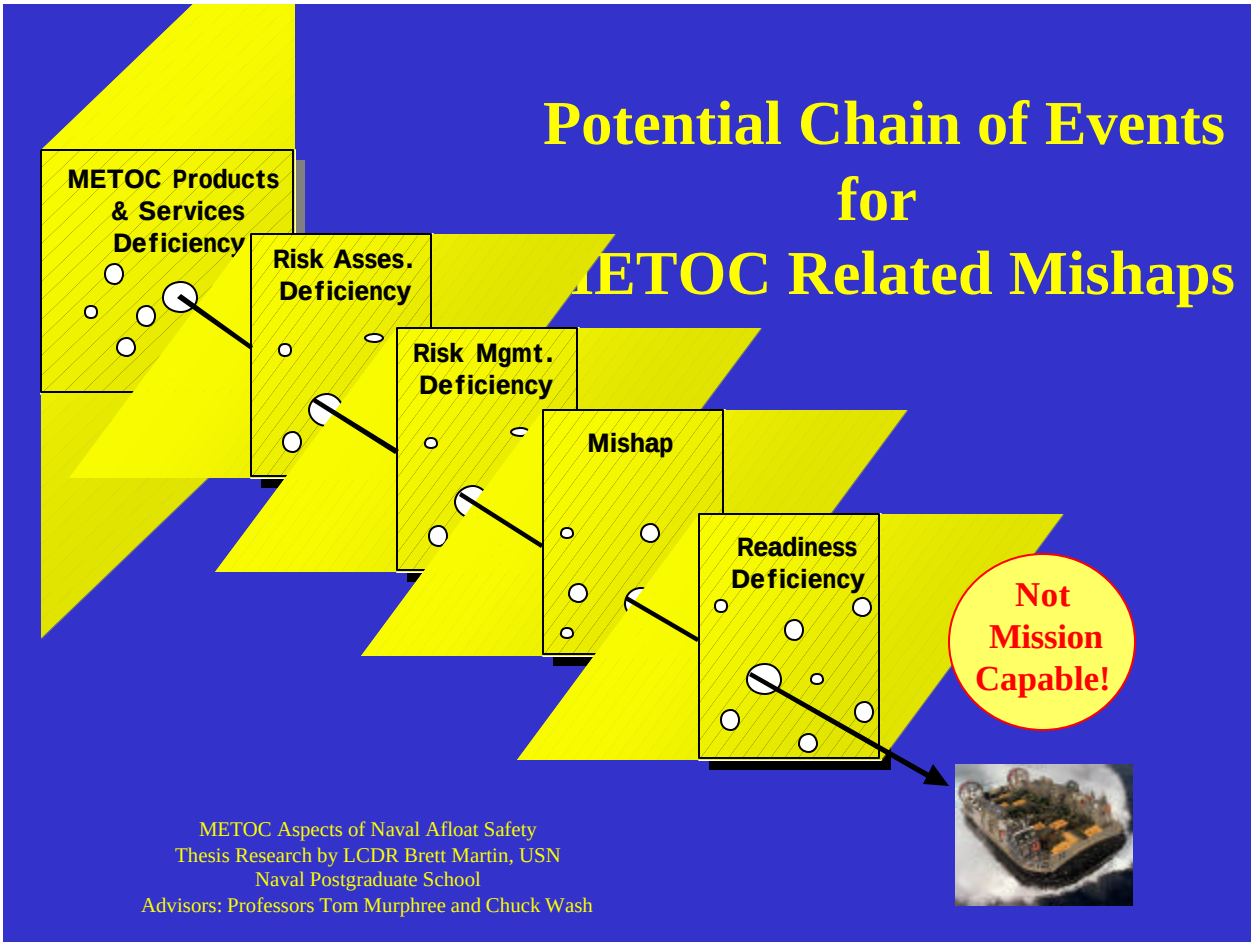
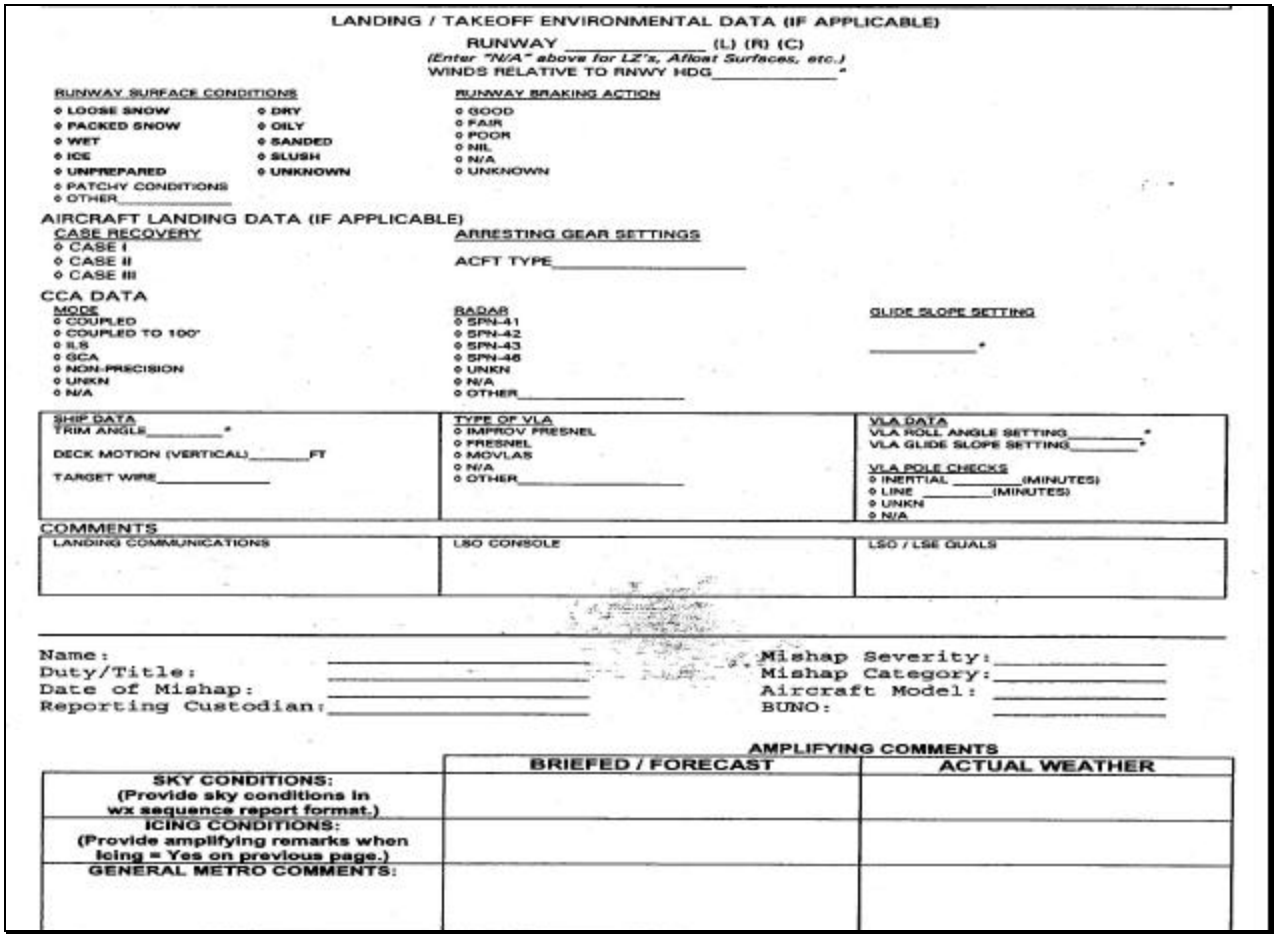


Figure 1. Potential Chain of Events for METOC Related Mishaps



LANDING / TAKEOFF ENVIRONMENTAL DATA (IF APPLICABLE)

RUNWAY _____ (L) (R) (C)
(Enter "N/A" above for LZ's, Afloat Surfaces, etc.)
WINDS RELATIVE TO RNWY HDG_____°

RUNWAY SURFACE CONDITIONS
◊ LOOSE SNOW ◊ DRY
◊ PACKED SNOW ◊ OILY
◊ WET ◊ SANDED
◊ ICE ◊ SLUSH
◊ UNPREPARED ◊ UNKNOWN
◊ PATCHY CONDITIONS
◊ OTHER_____

RUNWAY BRAKING ACTION
◊ GOOD
◊ FAIR
◊ POOR
◊ NIL
◊ N/A
◊ UNKNOWN

AIRCRAFT LANDING DATA (IF APPLICABLE)

CASE RECOVERY
◊ CASE I
◊ CASE II
◊ CASE III

ARRESTING GEAR SETTINGS
ACFT TYPE_____

CCA DATA

MODE
◊ COUPLED
◊ COUPLED TO 100'
◊ ILS
◊ GCA
◊ NON-PRECISION
◊ UNKN
◊ N/A

RADAR
◊ SPN-41
◊ SPN-42
◊ SPN-43
◊ SPN-46
◊ UNKN
◊ N/A
◊ OTHER_____

GLIDE SLOPE SETTING
_____°

SHIP DATA	TYPE OF VLA	VLA DATA
TRIM ANGLE_____° DECK MOTION (VERTICAL)_____FT TARGET WIRE_____	◊ IMPROV FRESNEL ◊ FRESNEL ◊ MOVLAS ◊ N/A ◊ OTHER_____	VLA ROLL ANGLE SETTING_____° VLA GLIDE SLOPE SETTING_____° VLA POLE CHECKS ◊ INERTIAL _____(MINUTES) ◊ LINE _____(MINUTES) ◊ UNKN ◊ N/A

COMMENTS

LANDING COMMUNICATIONS	LSO CONSOLE	LSO / LSE QUALS

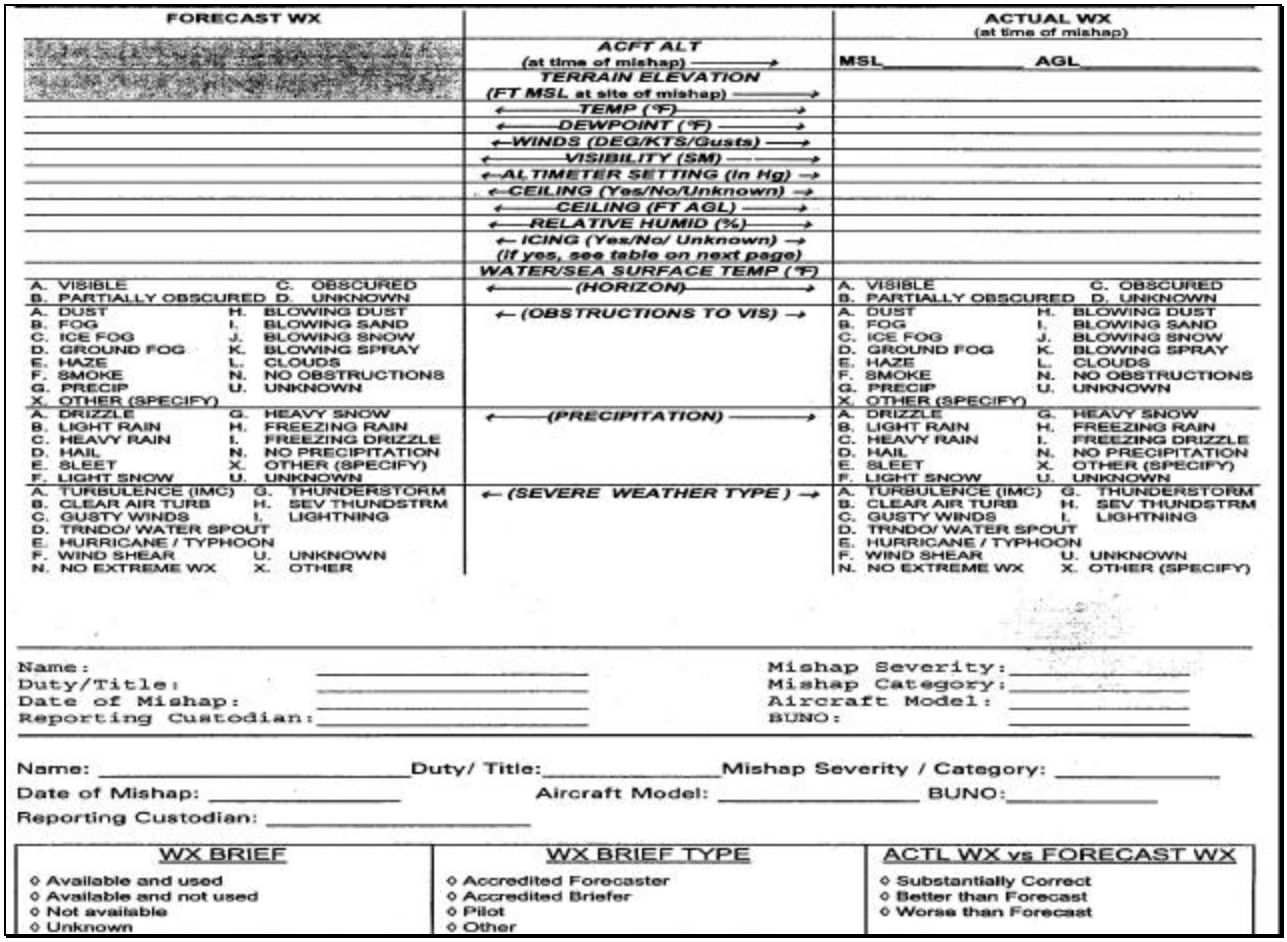
Name: _____
Duty/Title: _____
Date of Mishap: _____
Reporting Custodian: _____

Mishap Severity: _____
Mishap Category: _____
Aircraft Model: _____
BUNO: _____

AMPLIFYING COMMENTS

	BRIEFED / FORECAST	ACTUAL WEATHER
SKY CONDITIONS: (Provide sky conditions in wx sequence report format.)		
ICING CONDITIONS: (Provide amplifying remarks when Icing = Yes on previous page.)		
GENERAL METRO COMMENTS:		

Figure 2. Required METOC Information in Aviation Mishap Reports Part 1



FORECAST WX		ACTUAL WX (at time of mishap)
	ACFT ALT (at time of mishap) →	MSL AGL
	TERRAIN ELEVATION (FT MSL at site of mishap) →	
	← TEMP (°F) →	
	← DEWPOINT (°F) →	
	← WINDS (DEG/KTS/Gusts) →	
	← VISIBILITY (SM) →	
	← ALTIMETER SETTING (In Hg) →	
	← CEILING (Yes/No/Unknown) →	
	← CEILING (FT AGL) →	
	← RELATIVE HUMID (%) →	
	← ICING (Yes/No/ Unknown) → (if yes, see table on next page)	
	WATER/SEA SURFACE TEMP (°F)	
A. VISIBLE C. OBSCURED B. PARTIALLY OBSCURED D. UNKNOWN	← (HORIZON) →	A. VISIBLE C. OBSCURED B. PARTIALLY OBSCURED D. UNKNOWN
A. DUST H. BLOWING DUST B. FOG I. BLOWING SAND C. ICE FOG J. BLOWING SNOW D. GROUND FOG K. BLOWING SPRAY E. HAZE L. CLOUDS F. SMOKE N. NO OBSTRUCTIONS G. PRECIP U. UNKNOWN X. OTHER (SPECIFY)	← (OBSTRUCTIONS TO VIS) →	A. DUST H. BLOWING DUST B. FOG I. BLOWING SAND C. ICE FOG J. BLOWING SNOW D. GROUND FOG K. BLOWING SPRAY E. HAZE L. CLOUDS F. SMOKE N. NO OBSTRUCTIONS G. PRECIP U. UNKNOWN X. OTHER (SPECIFY)
A. DRIZZLE G. HEAVY SNOW B. LIGHT RAIN H. FREEZING RAIN C. HEAVY RAIN I. FREEZING DRIZZLE D. HAIL N. NO PRECIPITATION E. SLEET X. OTHER (SPECIFY) F. LIGHT SNOW U. UNKNOWN	← (PRECIPITATION) →	A. DRIZZLE G. HEAVY SNOW B. LIGHT RAIN H. FREEZING RAIN C. HEAVY RAIN I. FREEZING DRIZZLE D. HAIL N. NO PRECIPITATION E. SLEET X. OTHER (SPECIFY) F. LIGHT SNOW U. UNKNOWN
A. TURBULENCE (IMC) G. THUNDERSTORM B. CLEAR AIR TURB H. SEV THUNDSTRM C. GUSTY WINDS I. LIGHTNING D. TRNDO/ WATER SPOUT E. HURRICANE / TYPHOON F. WIND SHEAR U. UNKNOWN N. NO EXTREME WX X. OTHER	← (SEVERE WEATHER TYPE) →	A. TURBULENCE (IMC) G. THUNDERSTORM B. CLEAR AIR TURB H. SEV THUNDSTRM C. GUSTY WINDS I. LIGHTNING D. TRNDO/ WATER SPOUT E. HURRICANE / TYPHOON F. WIND SHEAR U. UNKNOWN N. NO EXTREME WX X. OTHER (SPECIFY)

Name: _____ Mishap Severity: _____
Duty/Title: _____ Mishap Category: _____
Date of Mishap: _____ Aircraft Model: _____
Reporting Custodian: _____ BUNO: _____

Name: _____ Duty/ Title: _____ Mishap Severity / Category: _____
Date of Mishap: _____ Aircraft Model: _____ BUNO: _____
Reporting Custodian: _____

WX BRIEF	WX BRIEF TYPE	ACTL WX vs FORECAST WX
◊ Available and used ◊ Available and not used ◊ Not available ◊ Unknown	◊ Accredited Forecaster ◊ Accredited Briefer ◊ Pilot ◊ Other	◊ Substantially Correct ◊ Better than Forecast ◊ Worse than Forecast

Figure 3. Required METOC Information in Aviation Mishap Reports Part 2

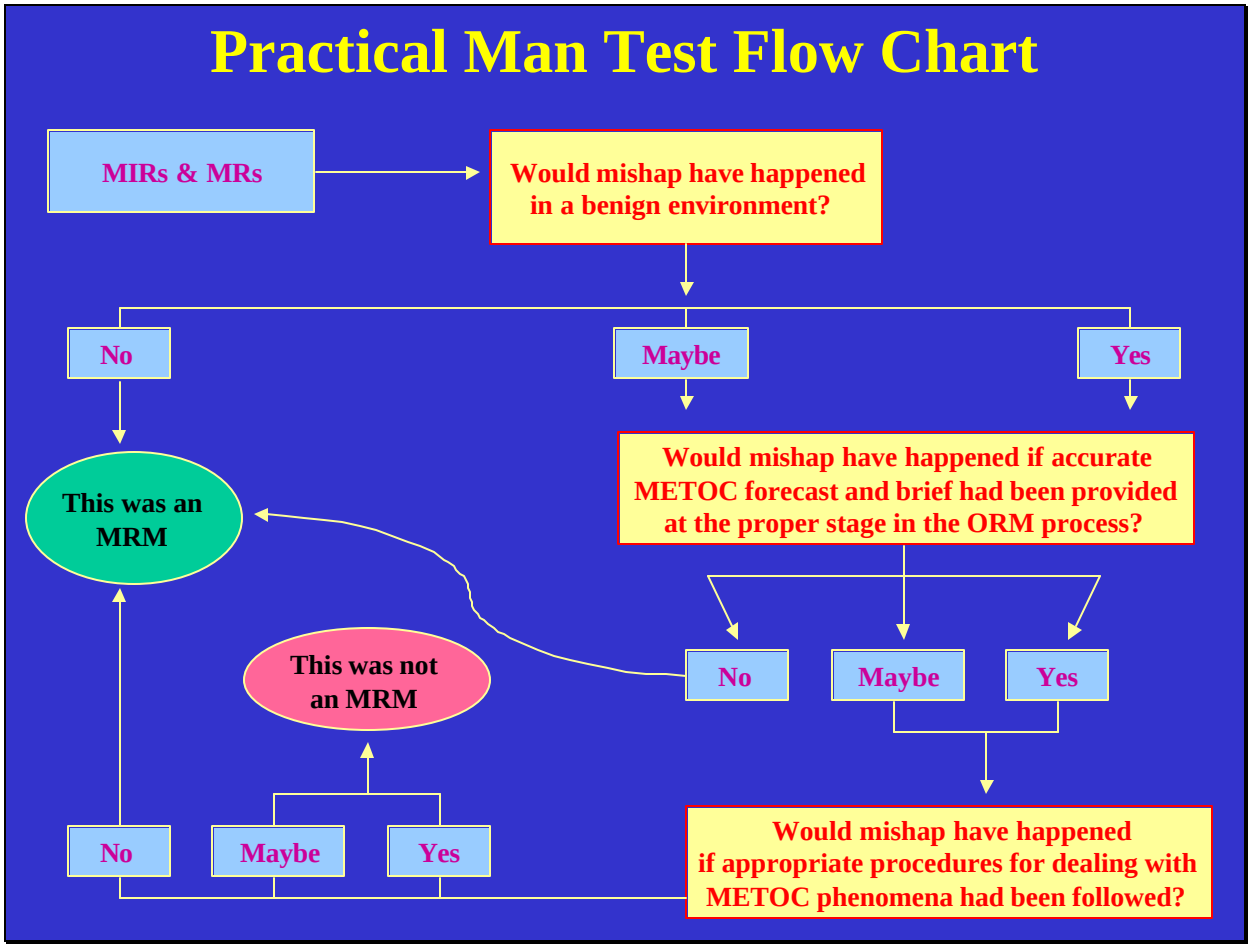

Practical Man Test Flow Chart
MIRs & MRs
Would mishap have happened in a benign environment?
No
Maybe
Yes
This was an MRM
Would mishap have happened if accurate METOC forecast and brief had been provided at the proper stage in the ORM process?
This was not an MRM
No
Maybe
Yes
No
Maybe
Yes
Would mishap have happened if appropriate procedures for dealing with METOC phenomena had been followed?

Figure 4. Practical Man Test Flow Chart

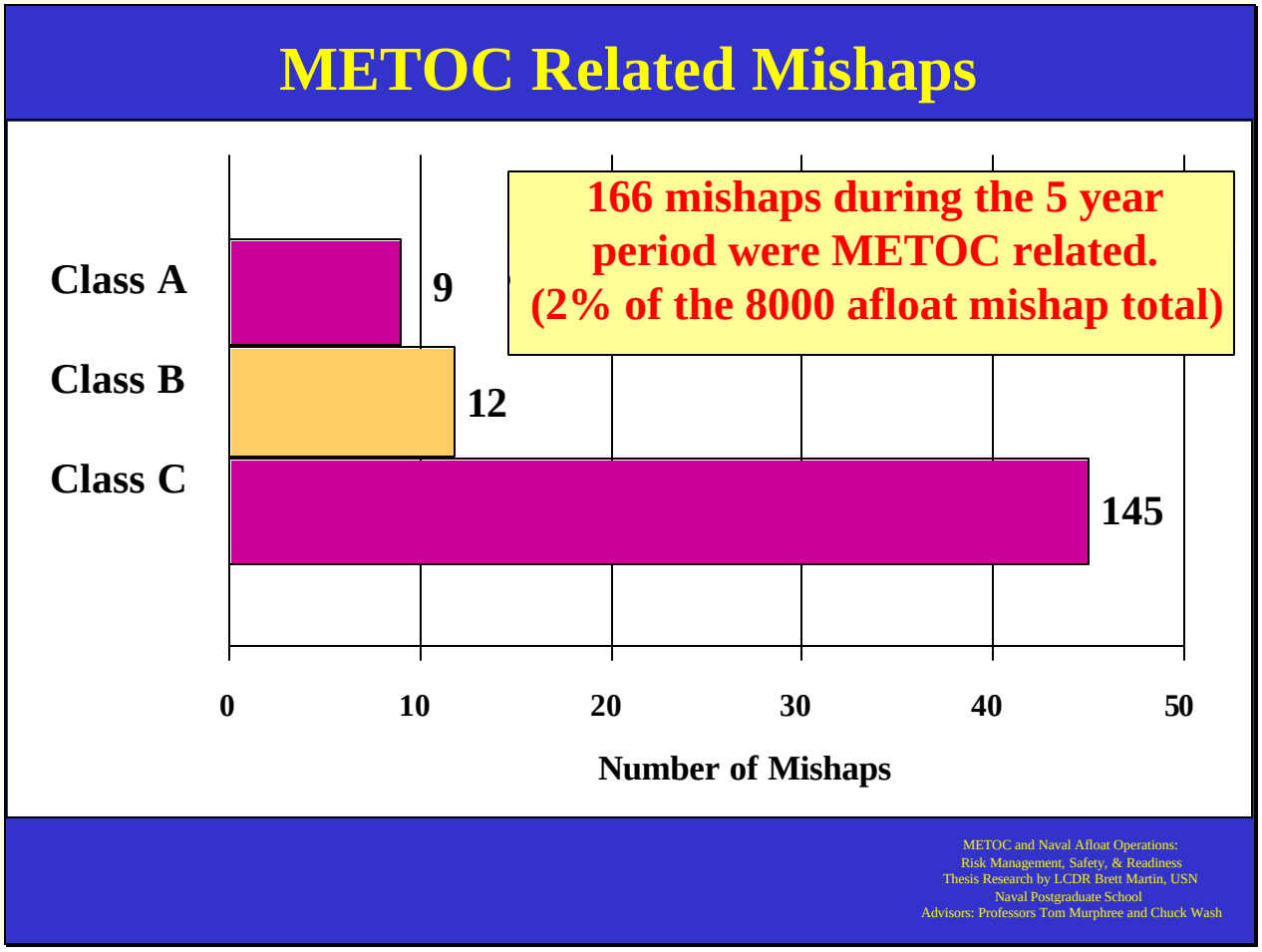


Figure 5. METOC Related Mishaps

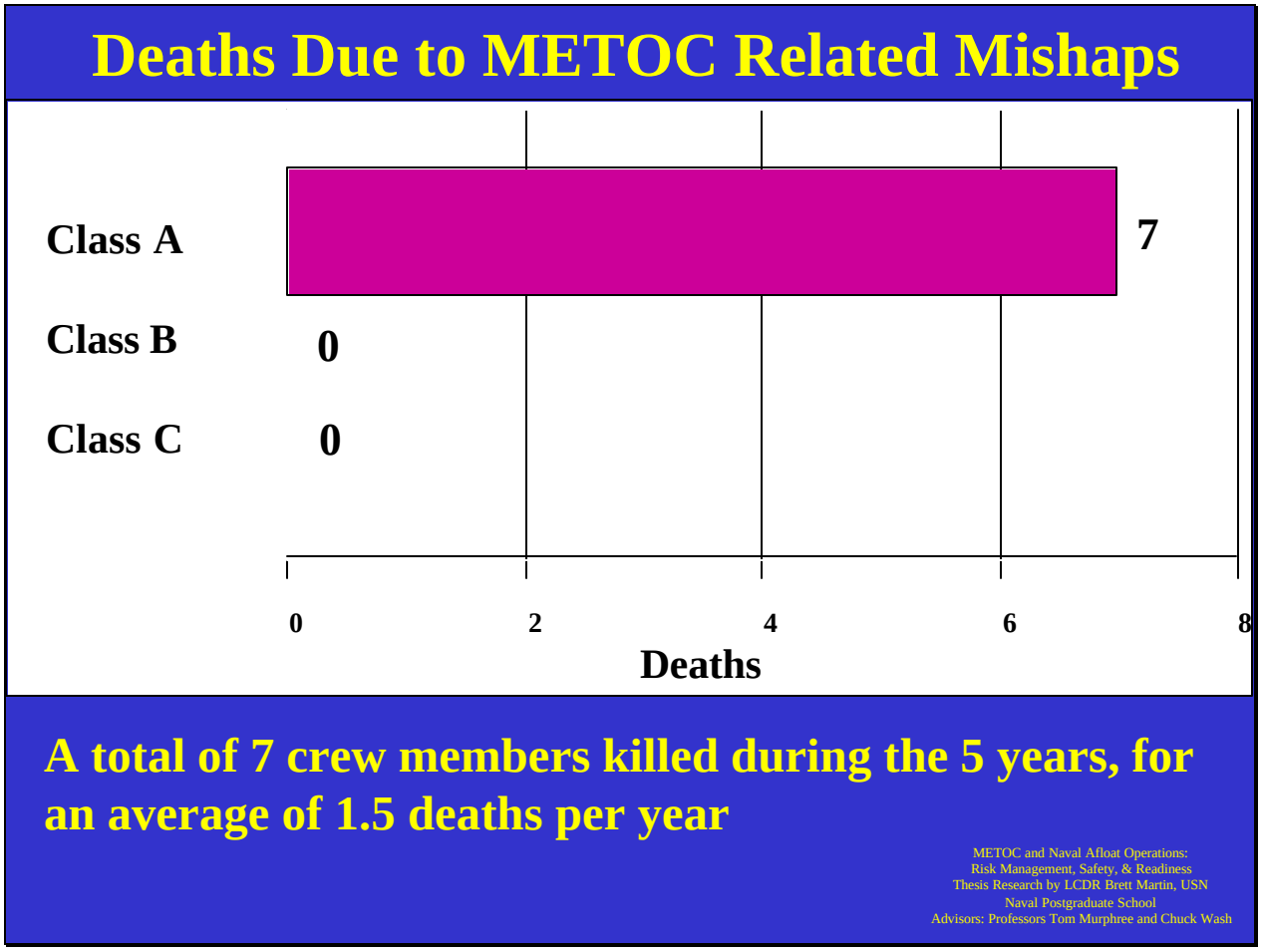


Figure 6. Deaths Due to METOC Related Mishaps

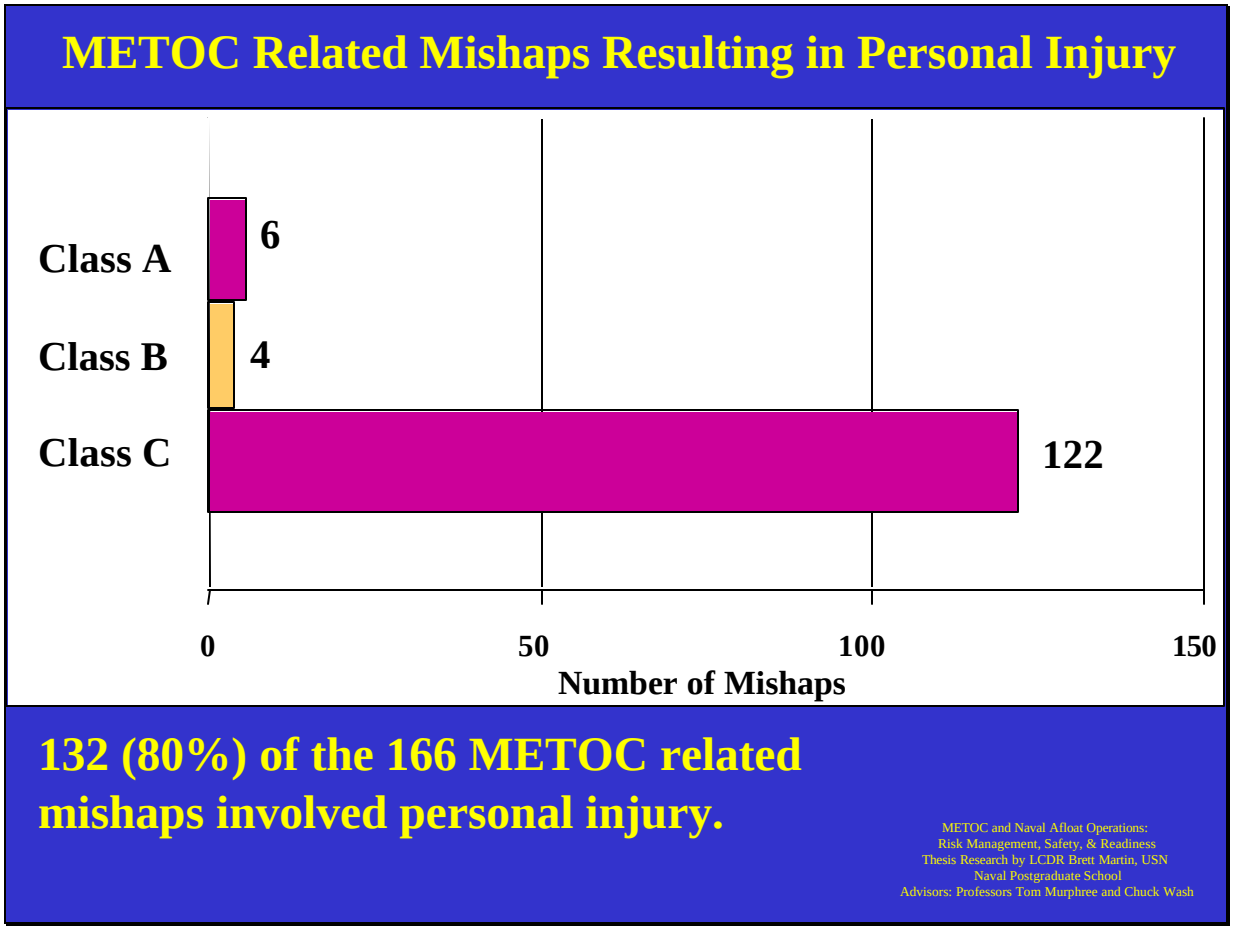


Figure 7. METOC Related Mishaps Resulting in Personal Injury

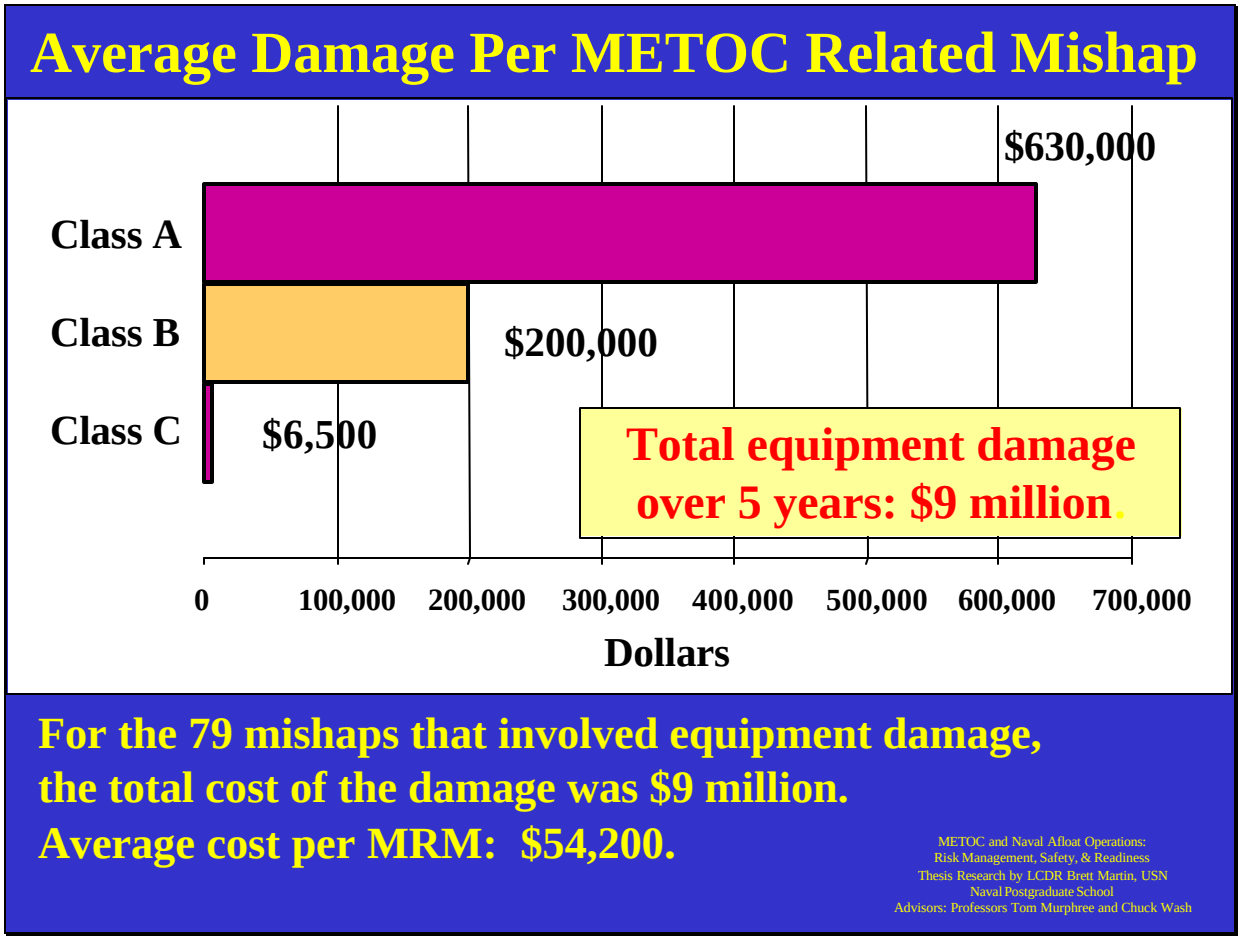


Figure 8. Average Damage Per METOC Related Mishap

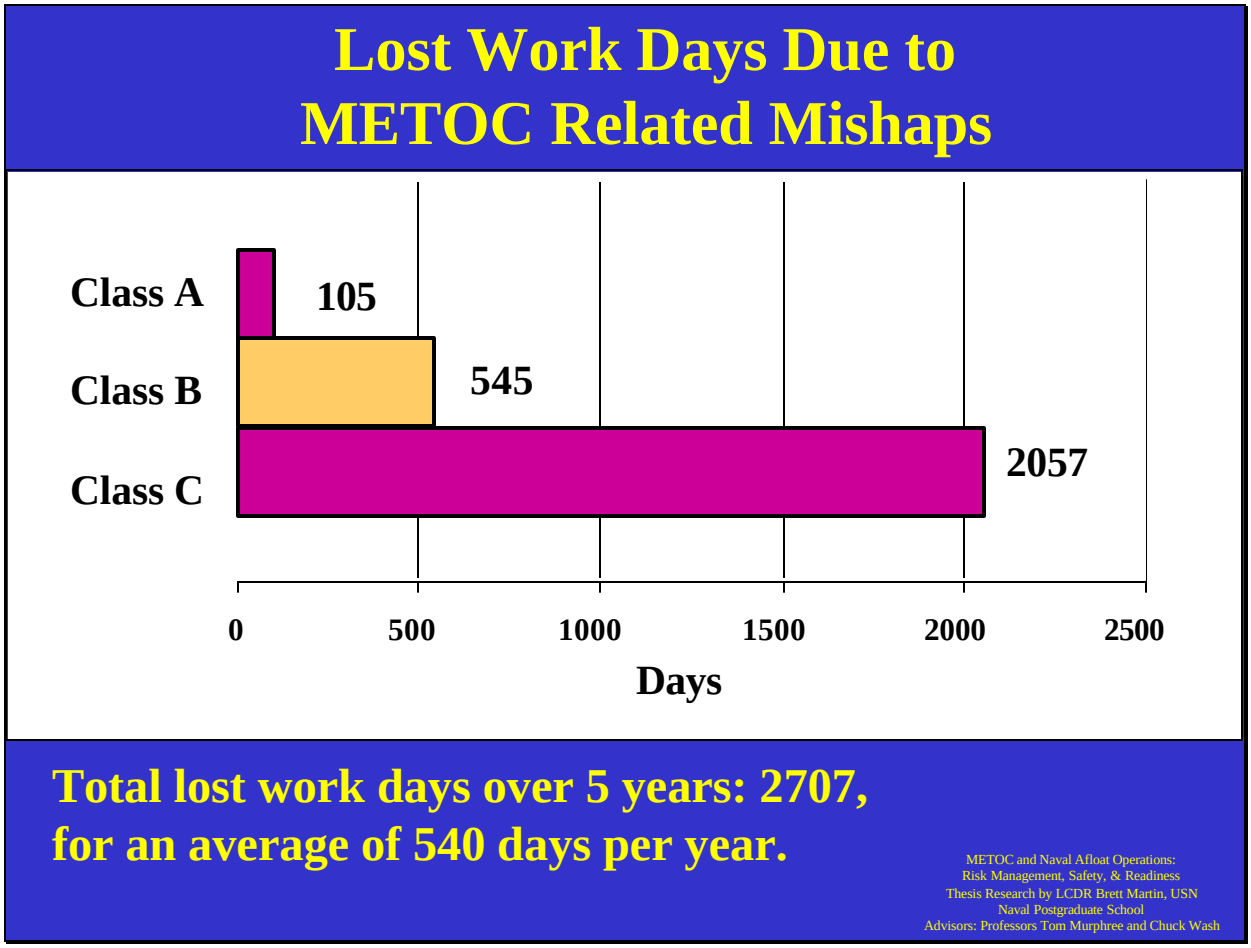


Figure 9. Lost Work Days Due to METOC Related Mishaps

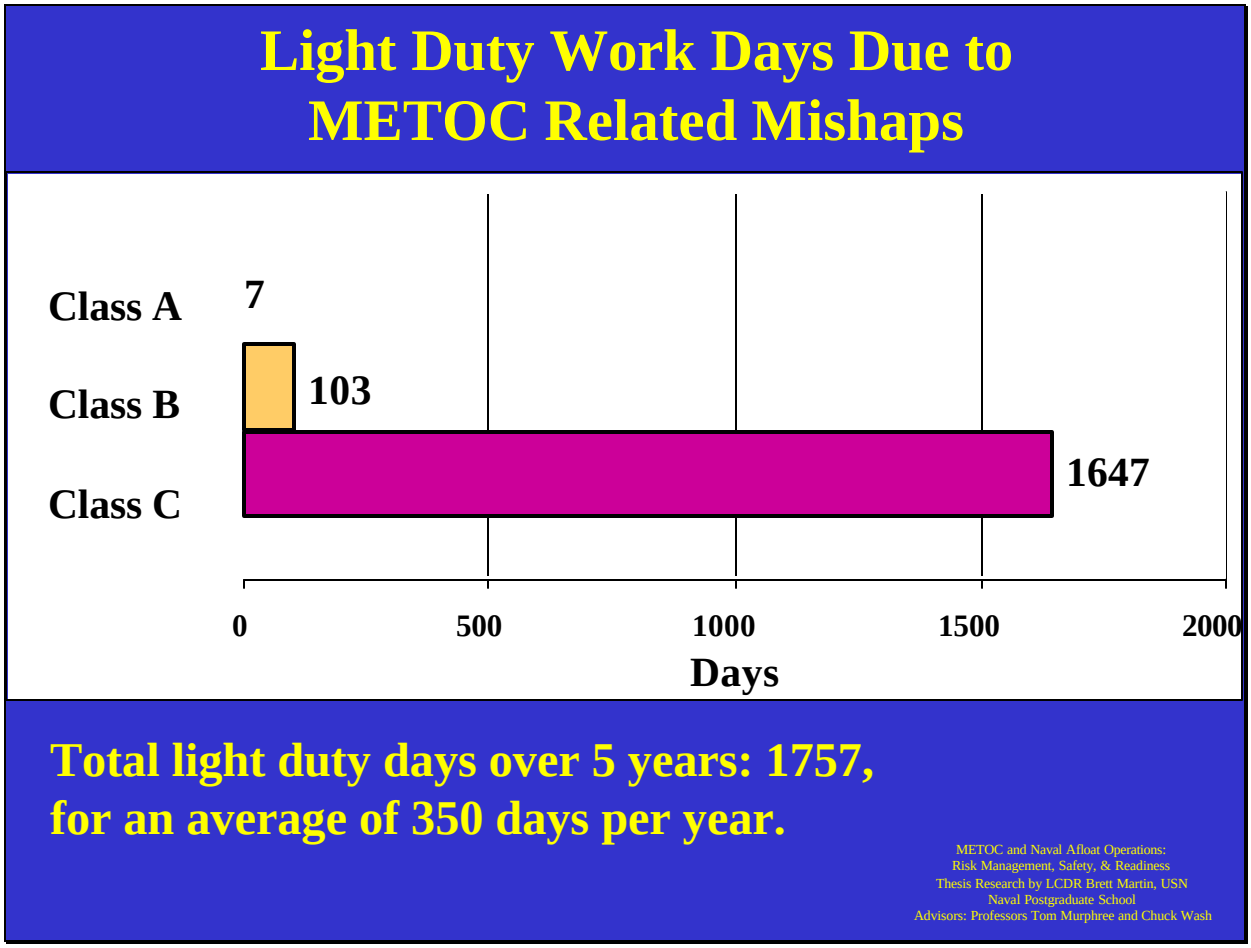
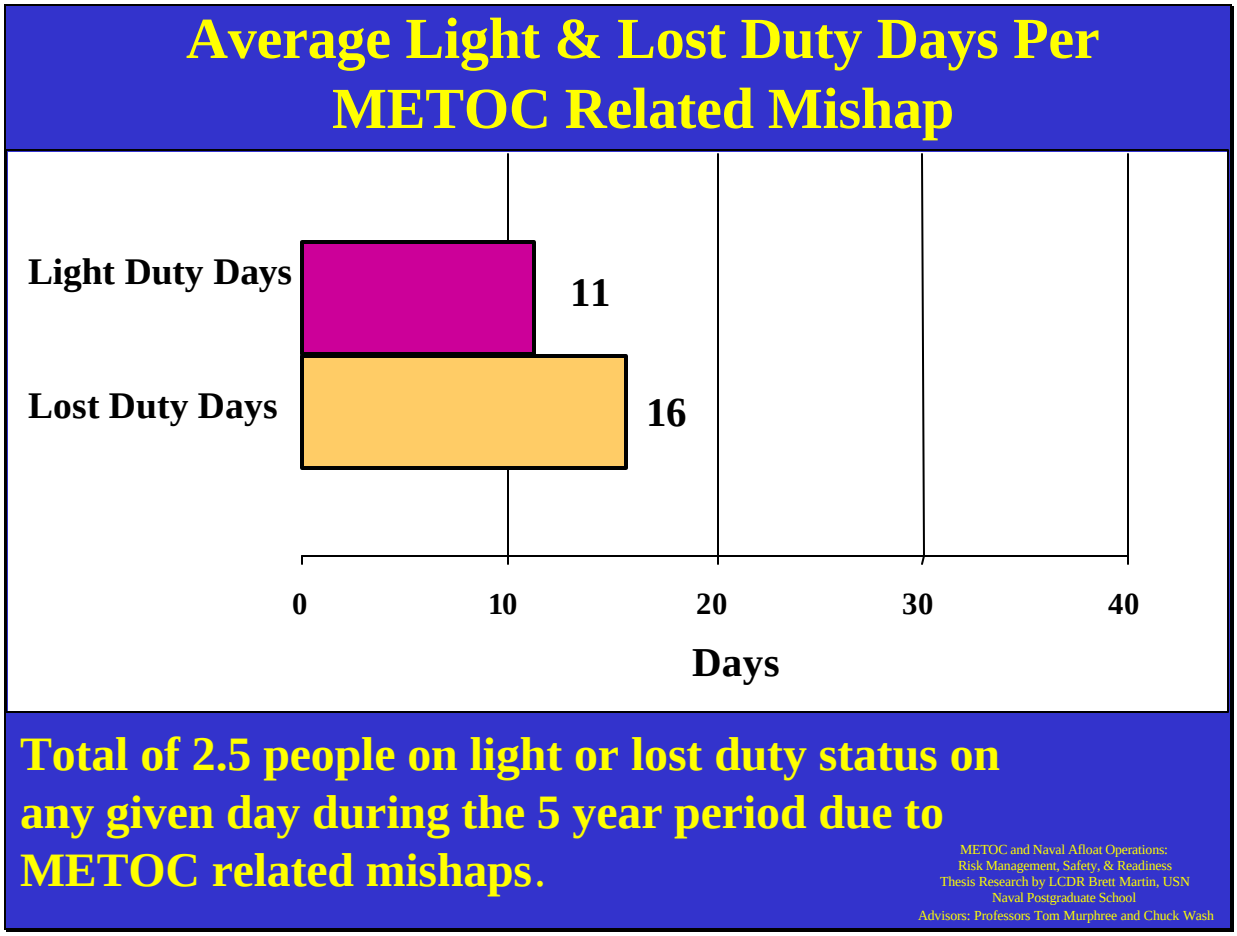


Figure 10. Light Duty Work Days Due to METOC Related Mishaps


Average Light & Lost Duty Days Per METOC Related Mishap
Light Duty Days
11
Lost Duty Days
16
0
10
20
30
40
Days
Total of 2.5 people on light or lost duty status on any given day during the 5 year period due to METOC related mishaps.
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Advisors: Professors Tom Murphree and Chuck Wash

Figure 11. Average Light & Lost Duty Days Per METOC Related Mishap

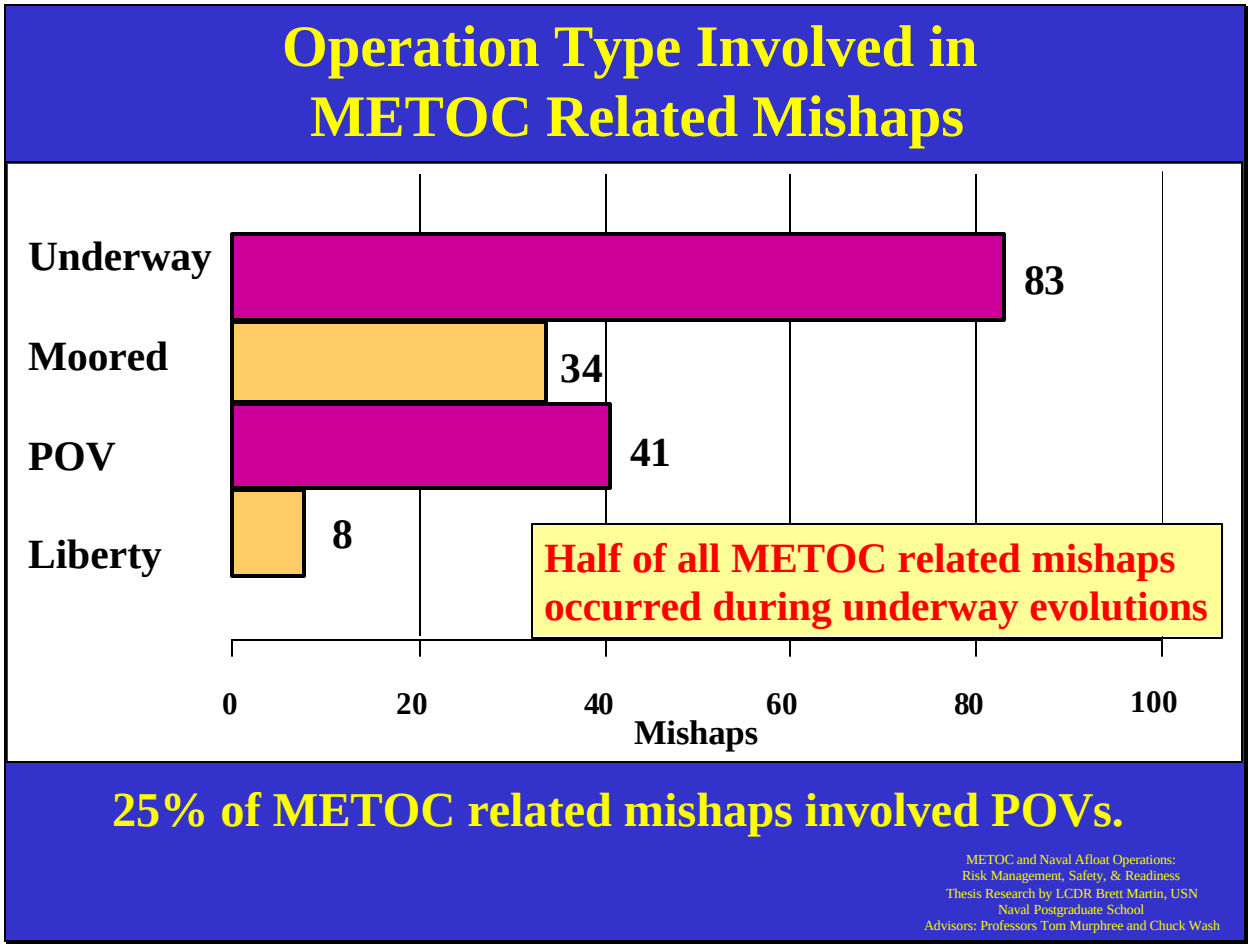

Figure 12. Operation Type Involved in METOC Related Mishaps

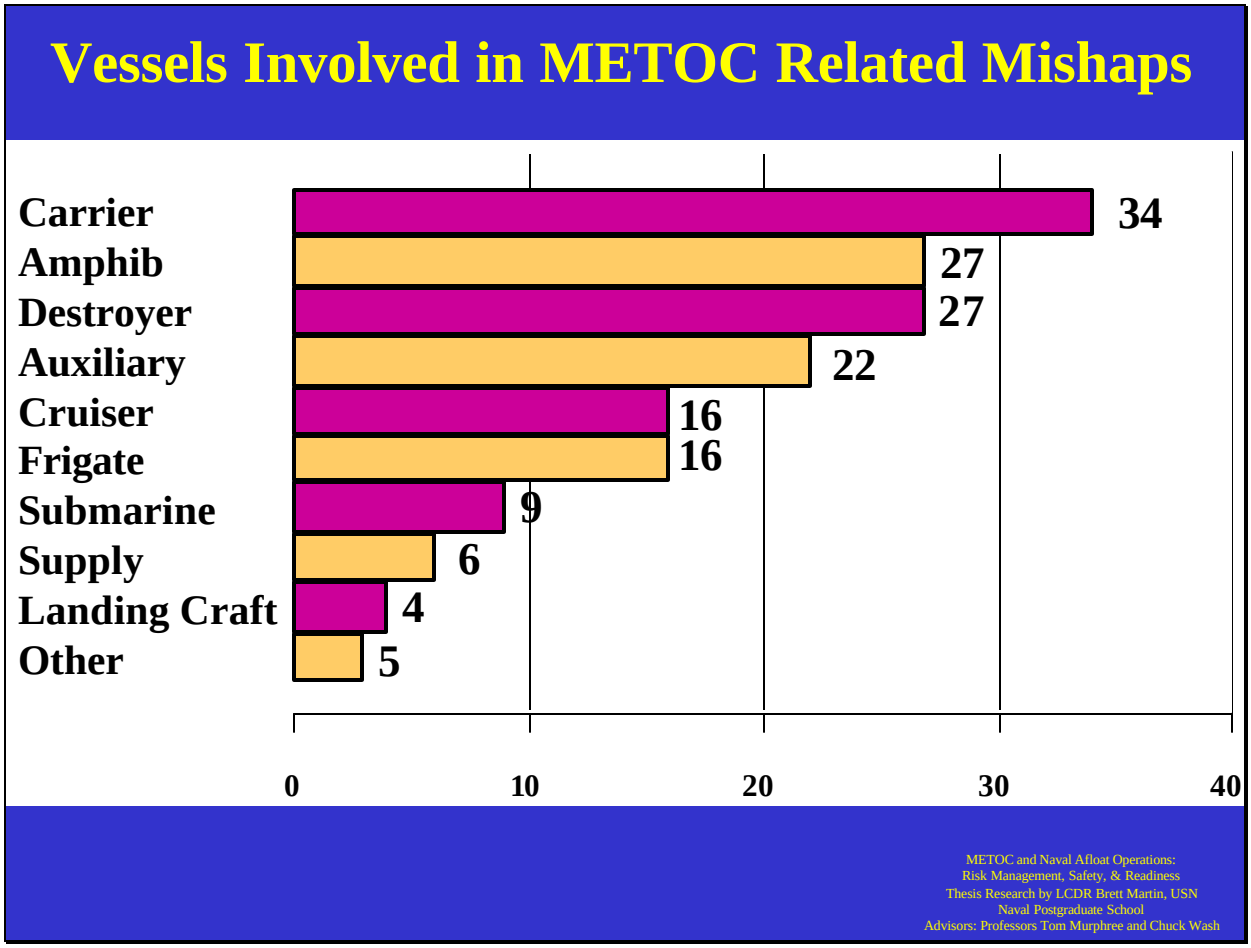

Figure 13. Vessels Involved in METOC Related Mishaps

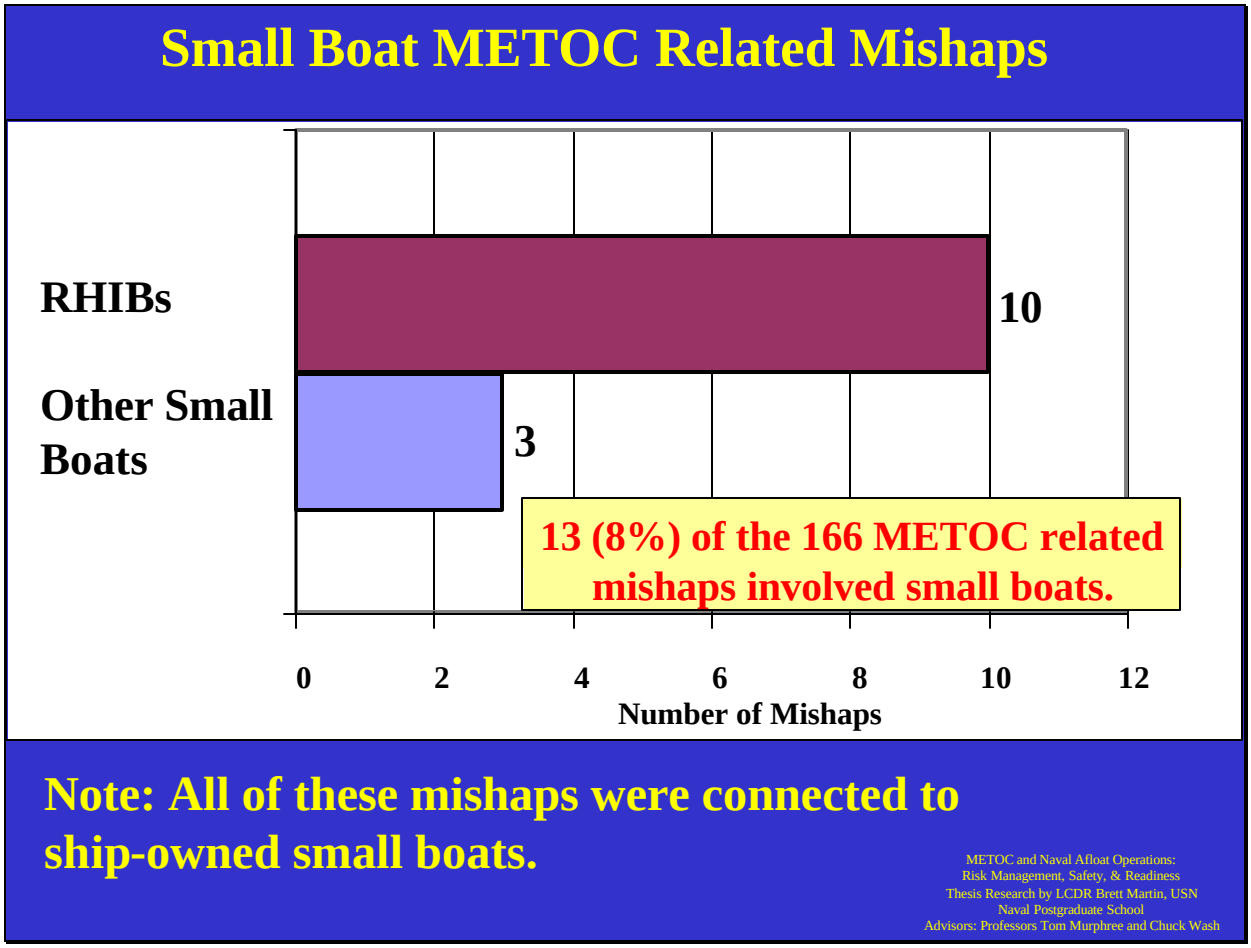

Figure 14. Small Boat METOC Related Mishaps

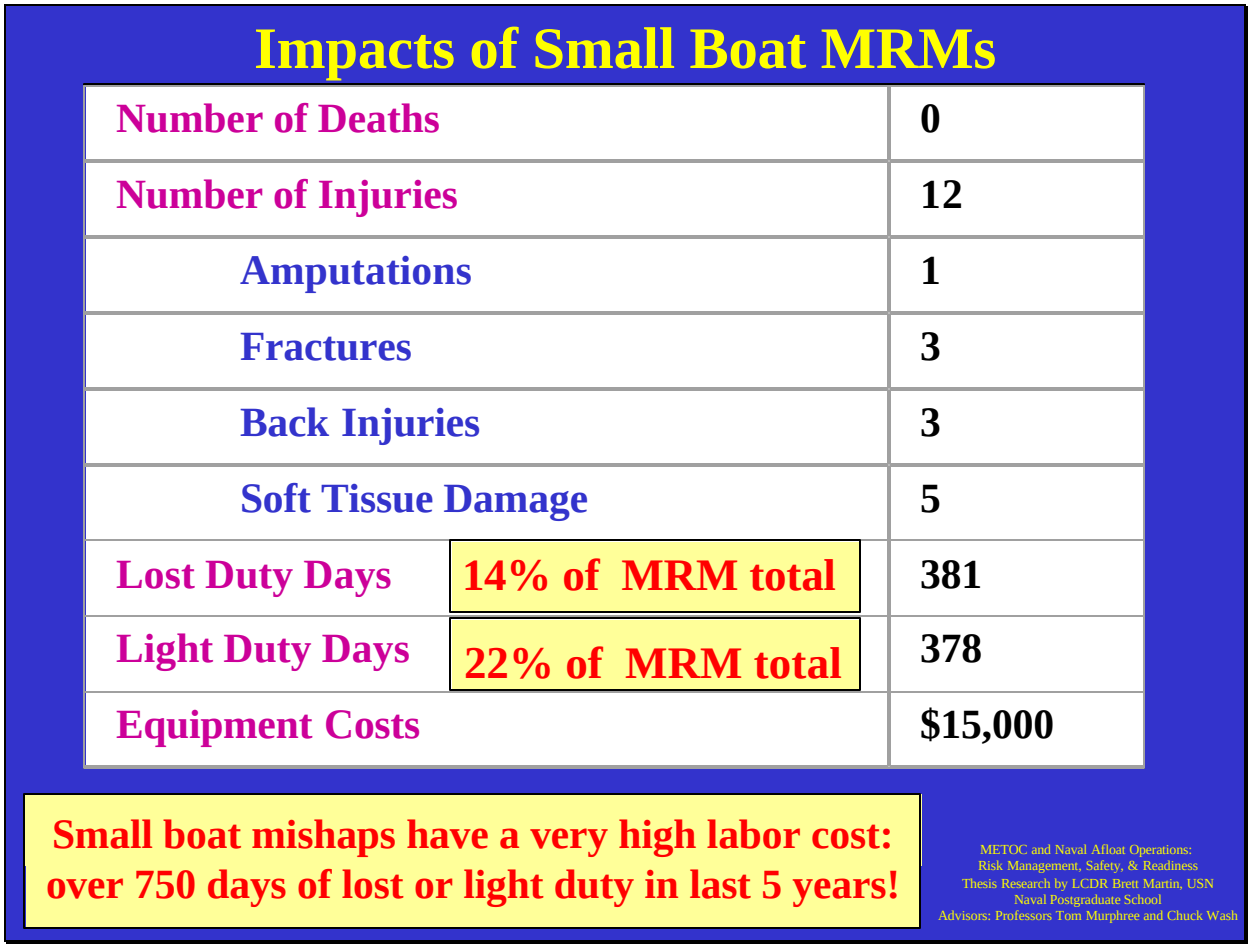

Figure 15. Impacts of Small Boat METOC Related Mishaps

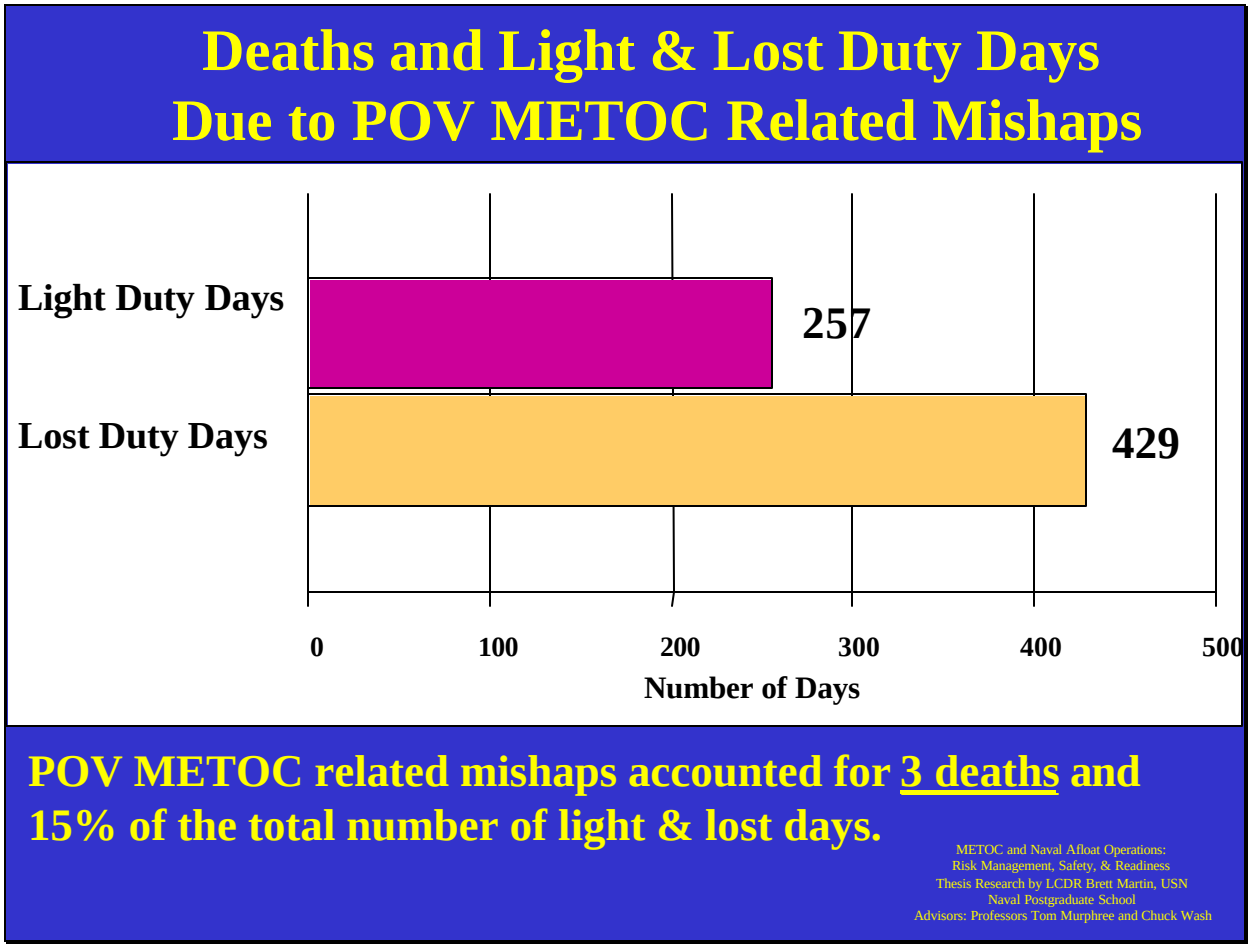

Figure 16. Deaths and Light & Lost Duty Days Due to POV MRMs

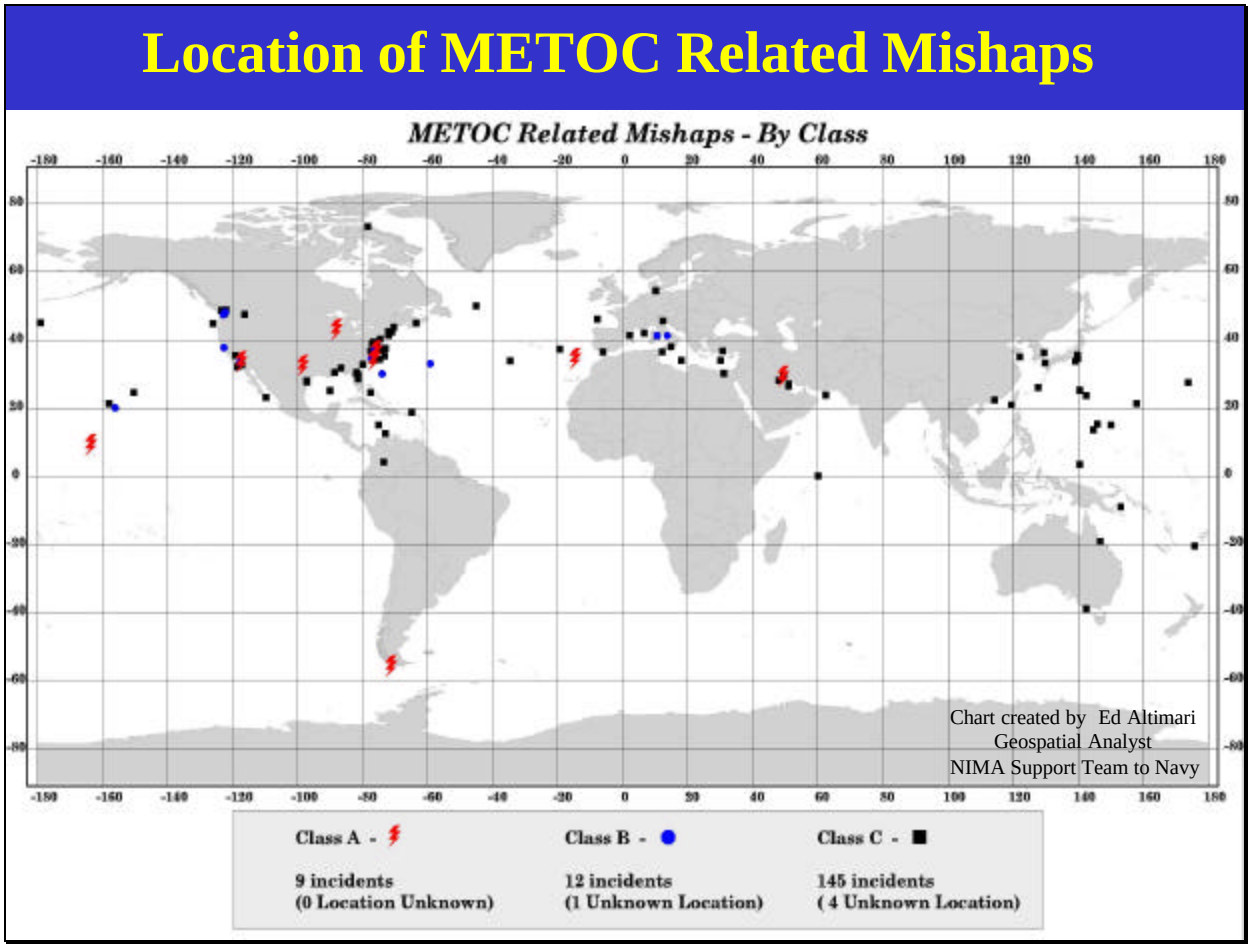

Figure 17. Locations of METOC Related Mishaps

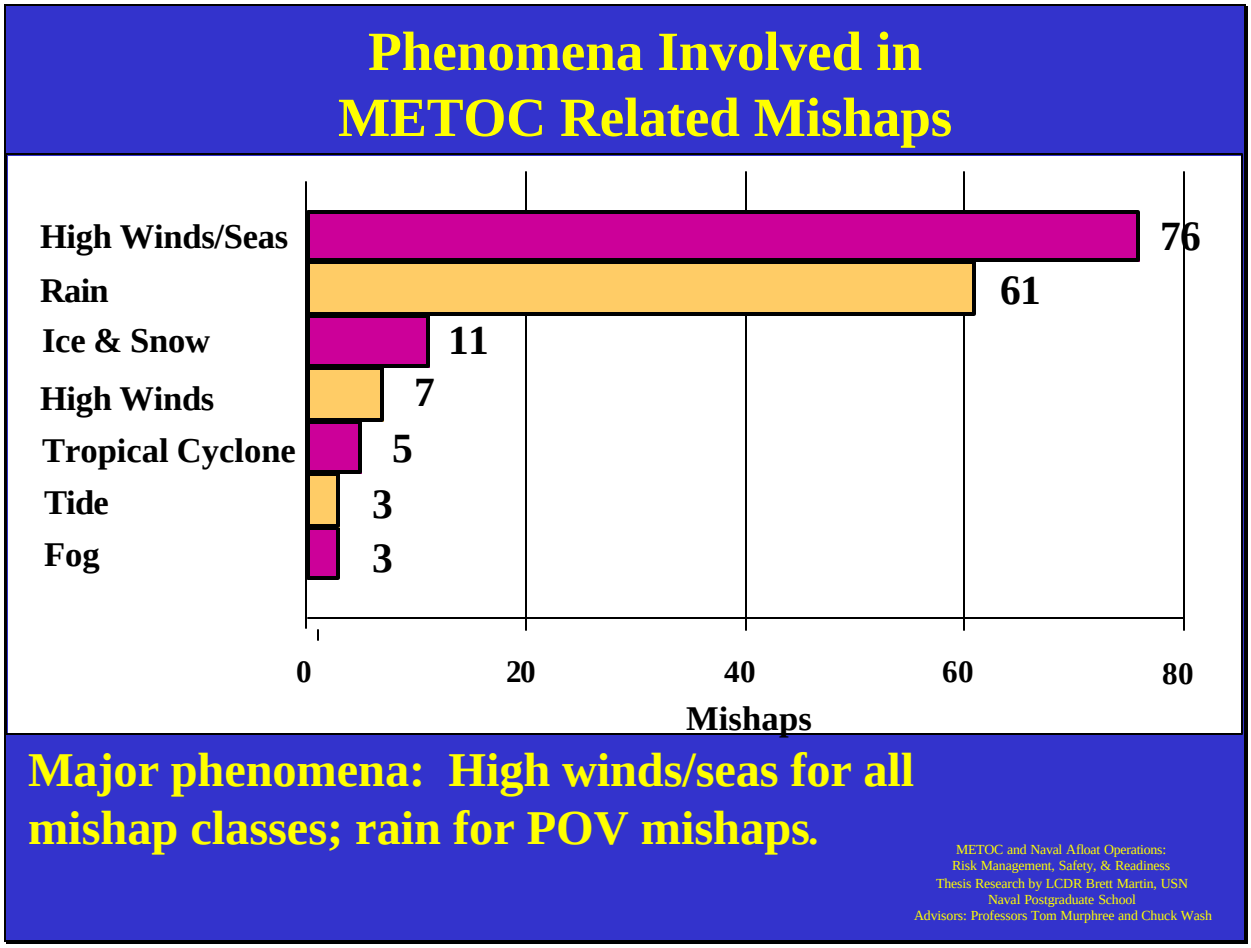

Figure 18. Phenomena Involved in METOC Related Mishaps

Tropical Cyclone Related Mishaps

	1997	1998	1999	2000	2001	Basin Total
NW Atlantic	2	1	5	0	0	8
NW Pacific	4	0	0	1	0	5
SW Pacific	1	1	0	0	0	2
Other Basins	0	0	0	0	0	0
Annual Total	7	2	5	1	0	15

Mishap reports identified only 5 TC related mishaps. Best track TC data revealed that 15 (9%) of the 166 MRMs were TC related.

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Figure 19. Tropical Cyclone Related Mishaps

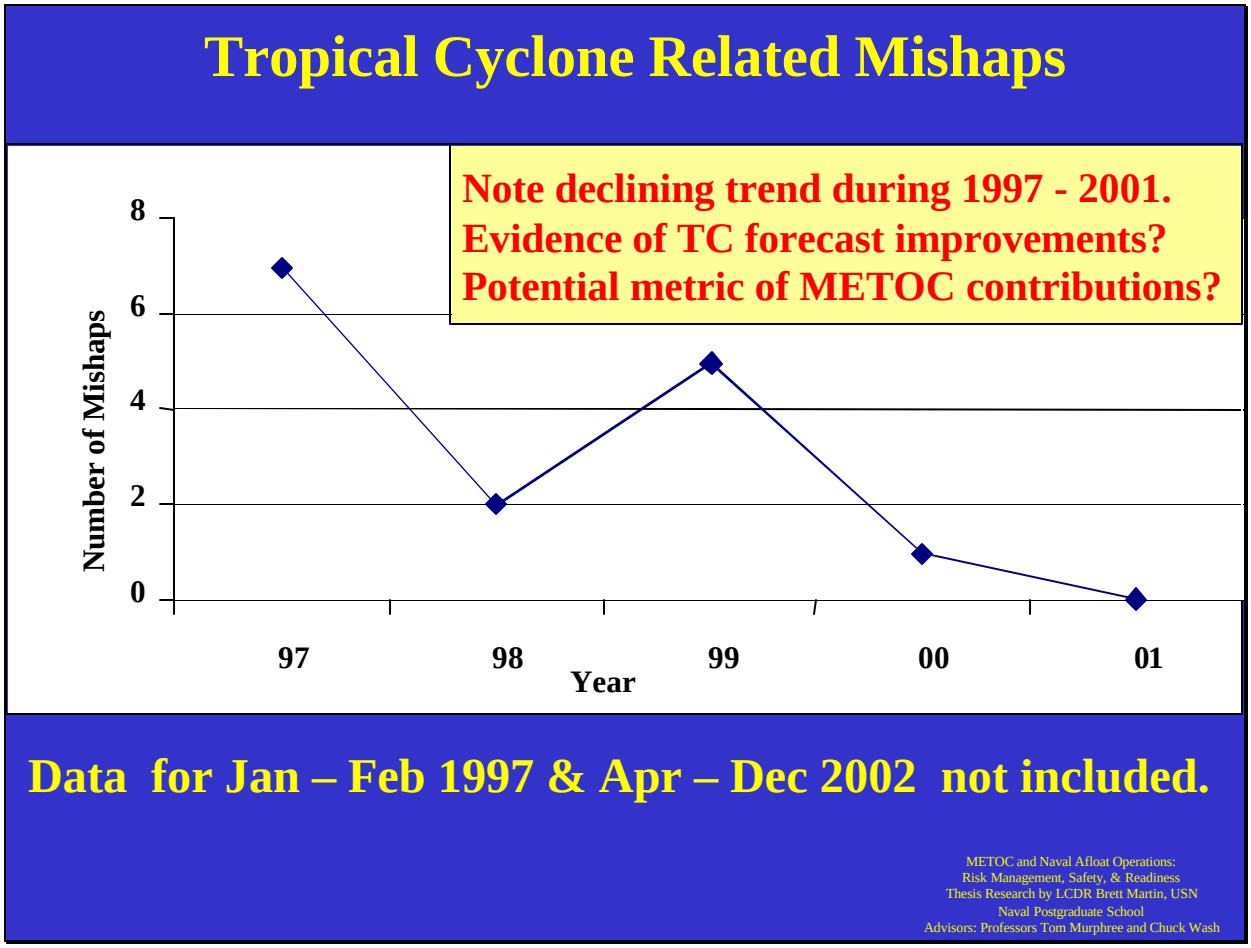

Figure 20. Tropical Cyclone Related Mishaps Time Series

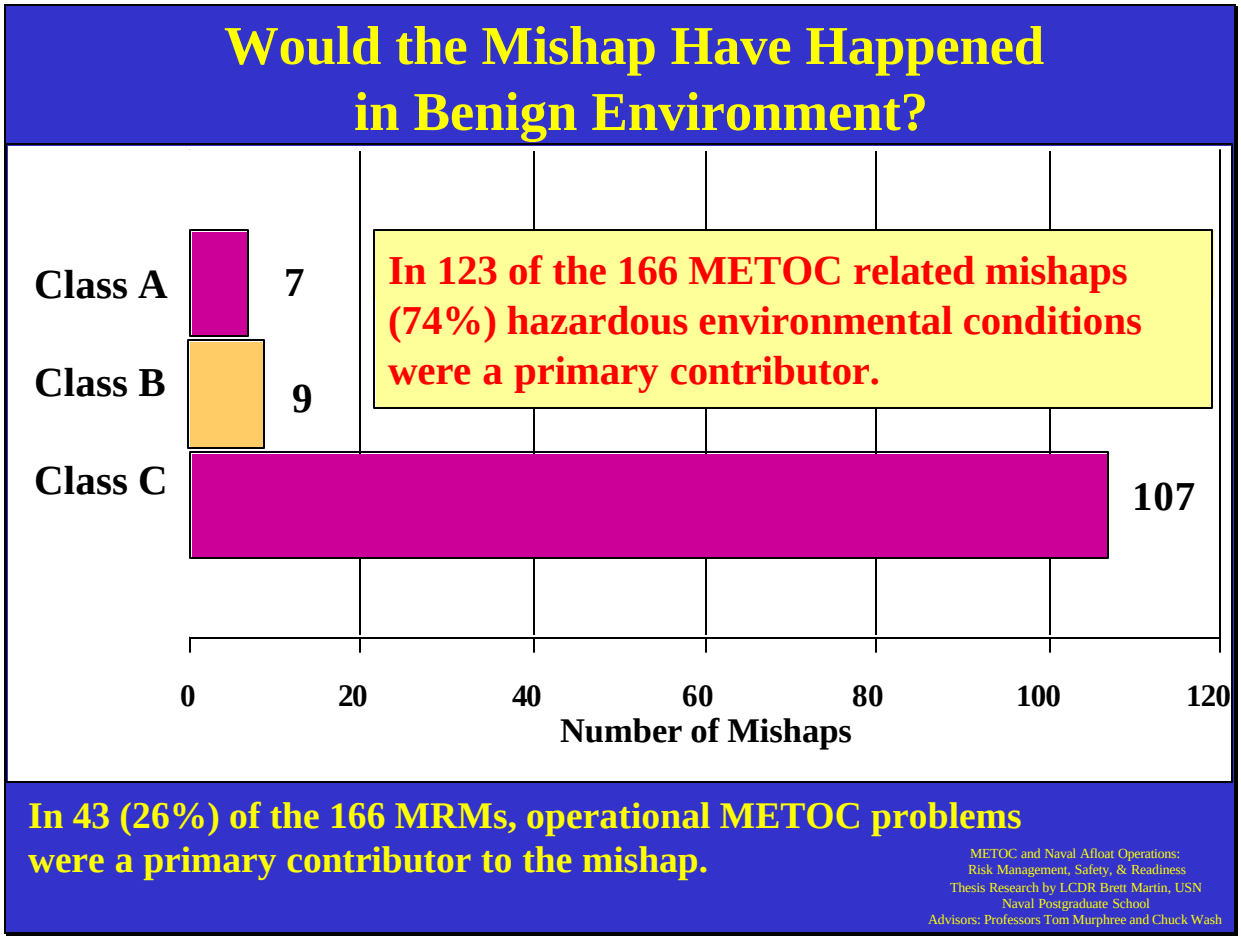
Would the Mishap Have Happened in Benign Environment?
Class A
7
Class B
9
Class C
107
In 123 of the 166 METOC related mishaps (74%) hazardous environmental conditions were a primary contributor.
0
20
40
60
80
100
120
Number of Mishaps
In 43 (26%) of the 166 MRMs, operational METOC problems were a primary contributor to the mishap.
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Figure 21. Would Have the Mishap Have Happened in Benign Environment

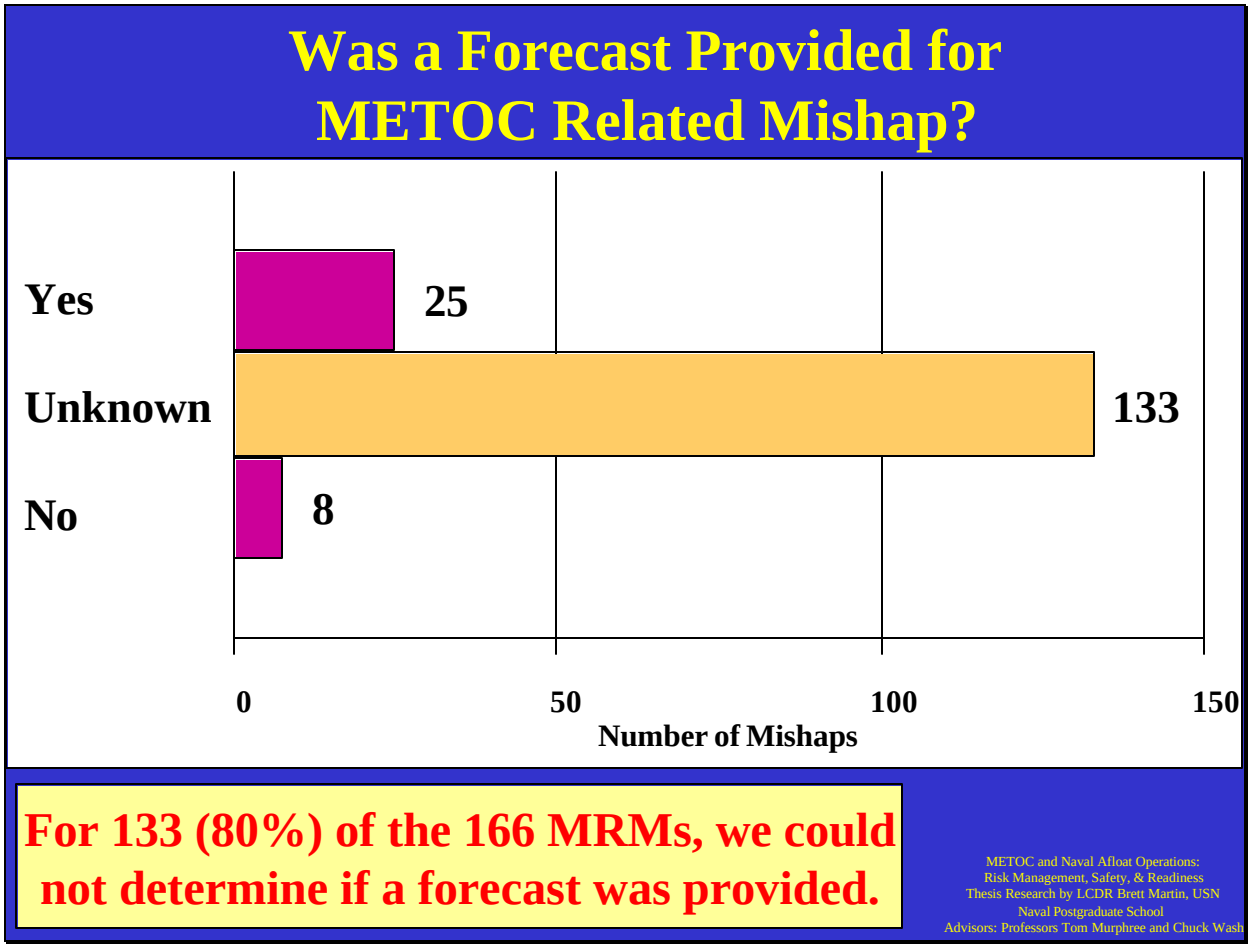

Figure 22. Was a Forecast Provided for METOC Related Mishap

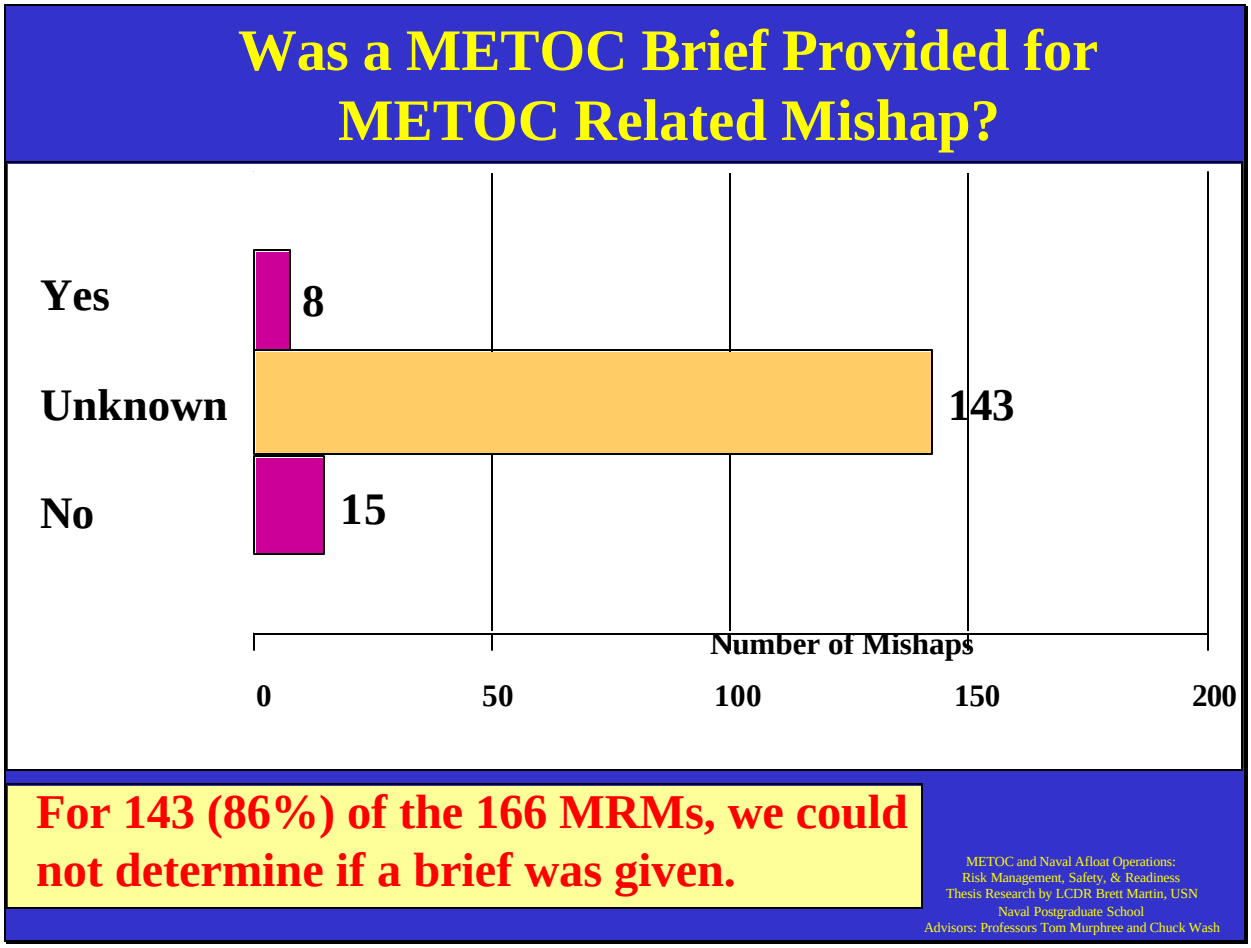

Figure 23. Was METOC Brief Provided for METOC Related Mishap

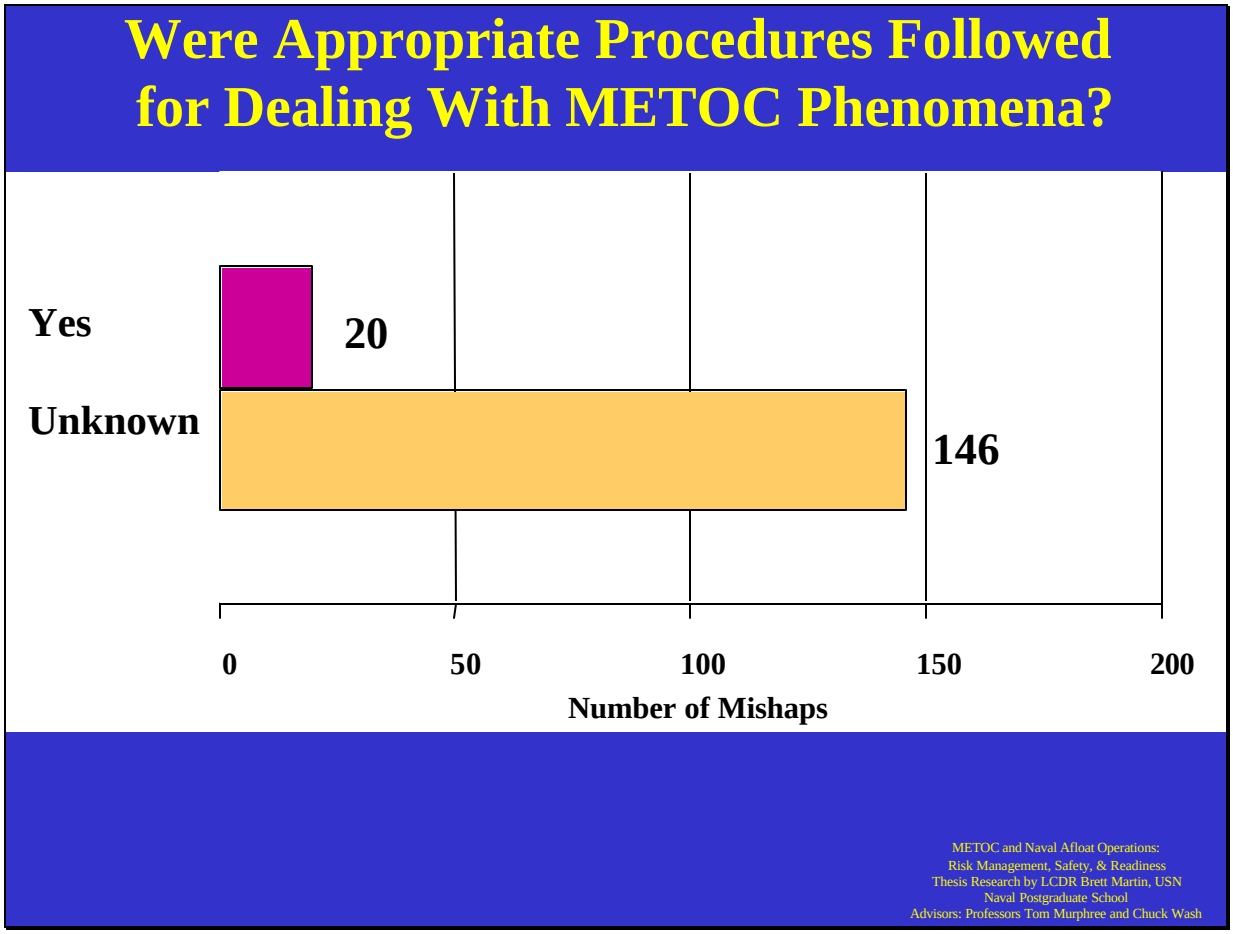

Figure 24. Were Appropriate Procedures Followed for Dealing with METOC Phenomena

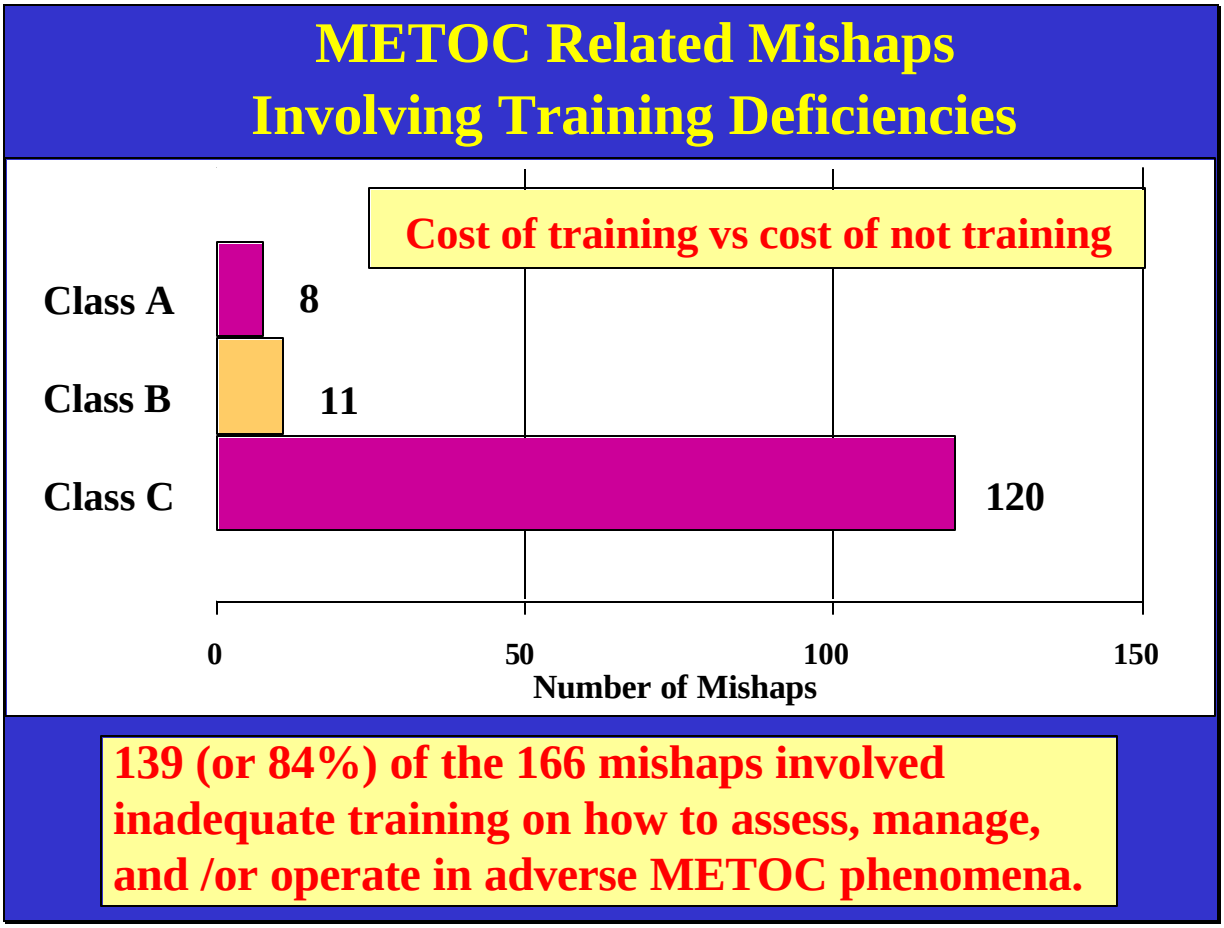

Figure 25. METOC Related Mishaps Involving Training Deficiencies

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